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THE WITWATERSRAND GOLD REGION, TRANSVAAL, SOUTH AFRICA, AS SEEN IN RECENT MINING DEVELOPMENTS[1]

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Location.—The name Transvaal is applied to a stretch of country lying north of the Vaal River and south of the Limpopo River. It comprises 106,642 square miles and is bounded on the south by the Orange River Colony and Natal, on the west by Cape Colony and Bechuanaland, on the north by Rhodesia, and on the east by Portuguese East Africa and Swazieland. From the lowlands along the Limpopo River the region rises gradually to the south and southeast, and in the southern part is an elevated plateau rising between five thousand and six thousand feet above the sea. This plateau is an open country, heavily covered with grass, with but few trees, and resembling in many respects some of our western states. It is capped by a low range of hills running about east and west and known as the Witwatersrand, or "white-water-ridge." This range is the divide between the waters of the Vaal and the Limpopo rivers, and in fact is the continental divide in this part of Africa, as the Vaal River runs into the Orange River and thence to the Atlantic, while the Limpopo River empties into the Indian Ocean.

[1] During a recent trip to South Africa the writer spent some time studying the occurrence of gold in the Witwatersrand region of the Transvaal. So much has already been written by others on this subject that it is not intended here to enter into a detailed description of the region, but only to discuss some of the more general features as seen in the light of recent developments.

On the southern slope of this divide, where it drops off toward the Vaal River, are the celebrated gold mines of the Witwatersrand, a name locally abbreviated to the Rand. The mines occur at frequent intervals for some fifty miles in a general east and west direction along the Rand, with the town of Johannesburg about midway along this line, while the ore-bearing formation has been traced even beyond these limits.

History.—Rumors of the gold of Africa have existed from the most remote times, some of them vague and indefinite, but some more specific, and there seems to be reason to believe that many sources of very ancient wealth were located there. Later on the Phoenicians are known to have bartered extensively in it, and the Arabs in the Middle Ages knew of it, and are supposed to have derived great wealth from it. The Portuguese explorers in the early part of the sixteenth century heard of it and made several more or less serious attempts to work it. It is probable, however, that most of the deposits known to them and to the earlier people were in the vast region extending from north of the Witwatersrand up to tropical Africa, though even in the Witwatersrand signs of old gold workings are said to have been found.

It was not, however, until the latter half of the nineteenth century that modern gold mining in the Transvaal was actively begun. In 1845 Von Buch, and some twenty years later Carl Mauch, reported gold in South Africa. It is said to have been discovered on what is now known as the Witwatersrand, or Rand, as early as 1854, but the Boers opposed its exploitation. In 1870 gold was discovered in the Murchison Range in northeastern Transvaal, and in 1873 mining was begun near Lydenburg, somewhat farther south. In 1875 gold was discovered in the DeKaap gold fields in eastern Transvaal, but active work did not begin until some years later. In 1885 the Sheba mine was discovered in the same region and the town of Barberton soon became a noted mining-center. A few years later, however, it was almost abandoned by the rush to the Witwatersrand. Placer gold mining had been carried on there in a small way for some time, but the first "reef" mining was begun in 1884 and 1885, and in 1886 Johannesburg was founded. From the start the industry grew until now the Witwatersrand is the greatest gold-mining district in the world.

Many other gold districts have been discovered in the Transvaal, Rhodesia, Natal, the Portuguese possessions, and other parts of South Africa, but the Witwatersrand still easily maintains its pre-eminence.

Geological relations of the gold deposits.—The gold of the Witwatersrand occurs as an impregnation of certain conglomerate beds which are members of a series of quartzites, conglomerates and slates known as the Witwatersrand system. These strata lie unconformably on

FIG. 1.—Underground photograph at the Nourse-Deep Mine, Witwatersrand District, Transvaal, showing dike and faulting in the gold-bearing conglomerate. The speckled rock in the picture indicates the conglomerate.

older rocks known as the Swazieland series and classed by the local geologists as Archaean.[1] The Witwatersrand system has as yet afforded no fossils, so that its exact age is not known, but judging from fossils found in overlying formations, the Witwatersrand rocks are supposed to belong at least as low as the lower part of the Paleozoic and possibly lower in the geological column.

The Witwatersrand system is divided into an upper and a lower series, though there is no unconformity between them, the only dif-

[1] Hatch and Corstorphine, *The Geology of South Africa*, 1895.

ference being that the lower series is composed largely of slates, with quartzites and rarely some thin conglomerates, while the upper series is composed largely of quartzites, with prominent conglomerates and some little slate. Sheets of diabase are interbedded with both the upper and lower series, and diabase dikes cutting the strata t ansversely are of frequent occurrence (Fig. 1). The whole Witwatersrand system is much faulted and broken, especially at the east and west ends of the district, making estimates of its thickness in some p'aces often very uncertain. It is known to vary considerably in thickness, however, in different parts of the region, being much thicker in the estern part of the Witwatersrand than in the eastern part. In the central part of the district the upper and lower series of the system are each about ten thousand feet or possibly somewhat more in thickness, giving an aggregate thickness for the whole system of approximately twenty thousand feet.[1] To the east they are thinner and to the west thicker.

The Upper Witwatersrand series has been divided by the South African geologists into several different formations, each one consisting largely of quartzite but marked by more or less prominent conglomerate beds. These conglomerates are locally known among the miners as "reefs," and the term has been retained in some of the local geological nomenclature. The divisions of the Upper Witwatersrand made by Hatch and Corstorphine[2] are, in a descending order, the Elsburg series, the Kimberley series, the Bird Reef series, the Livingstone Reef series, and the Main Reef series. The gold of the Witwatersrand mines occurs mostly in the Main Reef series, lying as it does at the base of the Upper Witwatersrand and just above the Lower Witwatersrand series. Small quantities of gold have been found elsewhere in the Upper Witwatersrand series, bu. rarely in paying quantities, though in some places extensive work has been done in search of it. Small quantities of gold have also been found in the Transvaal in other conglomerates than those of the Witwatersrand system, but have not become of great importance. This is

[1] Hatch and Corstorphine, *op. cit.*, pp. 108, 125.

[2] *The Geology of South Africa*, p. 122. Some doubt is expressed by these writers as to whether the Elsburg series belongs to the Upper Witwatersrand or to the overlying Ventersdorp system. This matter, however, is not of great importance in the present discussion, as almost all the profitable mines on the Witwatersrand are in the Main Reef series.

especially true of the conglomerates of the Black Reef series of the Potchefstroom system, which belongs considerably higher up in the geological column than the Witwatersrand system. A number of attempts have been made to work the Black Reef gold, but so far the success has been small, though in a few instances a certain amount of profit is said, at least temporarily, to have been obtained.

Besides its occurrence in conglomerates, gold is found under various other conditions in various places in the Transvaal, but these

FIG. 2.—Photograph of surface workings in the Crown Reef Mine, Witwatersrand District, Transvaal. The steeply dipping strata underneath the hoisting works on the right-hand side of the picture are the outcrop of the gold-bearing conglomerate.

occurrences are not within the scope of this article. Among them, however, may incidentally be mentioned the auriferous quartz veins in rocks of the Swazieland series in the Barberton region and near Pietersburg; the quartz veins in the rocks of the Dolomite series near Lydenburg and at Malmani; the quartz veins in rocks of the Pretoria series west of Pretoria and west of Krugersdorp as well as elsewhere; the placer workings in many places. The importance of all these occurrences, however, has proved small compared with the gold in the conglomerates of the Main Reef series of the Witwatersrand, the

latter being what has made the Transvaal pre-eminent as a gold producer.

Mode of occurrence of the gold deposits.—The Main Reef series, which, as just stated, carries most of the gold of the Witwatersrand district, contains several gold-bearing conglomerates separated by quartzites of a light-gray or greenish-gray color, dense, brittle, and of either a vitreous or hard sandy structure. More rarely slaty strata occur. On the extreme eastern part of the Rand the conglomerates

FIG. 3.—Underground photograph in the Ferreira-Deep Mine, Witwatersrand District, Transvaal, showing the gold-bearing conglomerate running diagonally across the picture. The speckled rock indicates the conglomerate.

often come close together and are sometimes all within a distance of a few feet of each other. To the west they are scattered over a greater thickness of strata, sometimes one hundred feet or more, measured vertically to the dip. This widening is due chiefly to the widening of the interbedded quartzites, though the conglomerates also increase to some extent. The conglomerate beds vary in number in different places, but certain of them have become especially prominent as gold-producers, the chief ones being known locally as the Main Reef and the South Reef, while the Main Reef Leader and the South Reef

Leader, are usually smaller but often rich beds. Other less important conglomerates are the North Reef, the Middle Reef, etc.

The Main Reef, from which the Main Reef series has received its name, is generally the largest, and ranges from a few feet to probably fifteen feet or more in thickness, though usually not of high grade. It outcrops along a general east and west course throughout the district, and dips in a southerly direction at angles which are often steep near the surface, frequently 80° or more (Fig. 2), and shows a tendency

FIG. 4.—Underground photograph in the Jumpers-Deep Mine, Witwatersrand District, Transvaal, showing the gold-bearing conglomerate running diagonally across the picture. The speckled rock indicates the conglomerate.

to flatten in depth, a dip of from 40° down to 20° or less being common at no great depth (Figs. 3, 4, and 5). The South Reef lies to the south of the Main Reef and is separated from it by intervening strata of a thickness of from a few feet to ninety feet or more. It is usually somewhat smaller than the Main Reef but is usually richer. It is parallel to, and shows the same variations in dip as the latter. The Main Reef Leader is a conglomerate bed almost immediately overlying the Main Reef and separated from it by only a few inches to a

few feet of intervening strata; in fact the two sometimes seem to come together. It varies from a few inches to several feet in thickness, but is usually thin, though often rich in gold. Sometimes, especially on the eastern part of the Witwatersrand district, a very persistent slaty parting occurs between the Main Reef and the Main Reef Leader, and is locally known as "the interbedded dike." Another small conglomerate, the South Reef Leader, lies immediately under the South Reef, and is also often rich in gold. The Middle Reef is a very low-grade body of conglomerate ore lying between the Main and South Reefs; and the North Reef is also a low-grade bed lying below the Main Reef.[1]

Sometimes still other conglomerate beds than those mentioned occur, while at other times some of the beds mentioned are wanting. In fact the conglomerates are more or less lenticular strata, widening and thinning at intervals, and sometimes disappearing altogether. In some places two or more beds may blend into one, or any one bed may be split up into two or more beds separated by quartzite; so that in different localities, a different number of conglomerates may be found, and those that have been described above are simply those that are usually the most continuously represented. Sometimes what seem to be the same conglomerates change their positions slightly in the associated strata and are a little higher or a little lower in one place than in another, while sometimes the formation is very much faulted, so that it is often difficult to correlate certain beds in different places. On the whole, however, the conglomerates, as compared with conglomerates elsewhere, may be said to be remarkably continuous over long distances, and this feature of the ore bodies has been one of the chief factors in the wonderful development of the mining operations of the region.

Though the conglomerates mentioned all carry gold, yet the quantity varies considerably in the different beds and even in different places in the same bed. The main Reef, though large, is generally of rather low grade, but it is worked in many places at a good profit. The South Reef and the Leaders are usually of higher

[1] Some of the reefs mentioned here are sometimes known by different names in different parts of the district, but the names given above are those most commonly used.

grade, one or both of the Leaders often being of much better grade than either the Main or South Reef. Though the conglomerates carry most of the gold, in fact all the gold that is mined in the Main Reef series, yet small quantities have been found in some of the quartzites.

The gold-bearing rocks of the Witwatersrand district, dipping, as they do, in a southerly direction, occupy the northerly side of a synclinal fold and come to the surface again in the Heidelberg dis-

FIG. 5.—Underground photograph at the Durban-Roudepoort-Deep Mine, Witwatersrand District, Transvaal, showing old workings from which the ore has been removed.

trict, some thirty miles southeast of Johannesburg, and on the Vaal River still farther south. More or less gold mining has been carried on in these more southerly districts, but much less extensively than in the Witwatersrand district. On the Witwatersrand the gold formation can be traced along its strike for over sixty miles, and at either end it disappears beneath younger strata. The claim is made, however, that it has been traced with the assistance of borings for over one hundred and sixty miles, and that there is more or less evidence of its extent, though interrupted by faults and covered by more recent strata, for over three hundred miles. So far, however,

none of the outlying districts have become very great producers, while even in the Witwatersrand district it is in only certain parts that highly remunerative results have been obtained. The conglomerates seem to be richest in the central part of the district, and to decrease in value on the east and the west ends. A large percentage of the gold comes from the mines along some twenty-five or thirty miles of the central part of the district, but for a distance of some fifty miles, east and west, there are scattered considerably over a hundred mines. Such a record, both for the number of mines in a given distance on one deposit, and for the percentage of profitable ones among this number, is probably unprecedented anywhere else.

Nature of the ore.—The ores of the Witwatersrand district consist, as already stated, of conglomerates impregnated with gold, and are frequently known by the Boer term "banket." The conglomerates, in their general character, do not differ from many conglomerates in other parts of the world except in their content of gold. The pebbles are well rounded and vary from a small fraction of an inch to several inches in diameter, most of them probably ranging from about a quarter of an inch to about an inch and a half or two inches. They are imbedded in a sandy matrix cemented by secondary silica, which knits them into a solid mass, and often forms small lenses, or irregular bodies of quartz, in the conglomerate. The rock thus cemented is massive and compact, and when broken the fracture often passes through the pebbles as readily as around them. Iron pyrites and marcasite are abundant, and a greenish chloritic or sericitic material often occurs encircling the pebbles and impregnating the matrix. Flakes of muscovite are not uncommon, and under the microscope other minerals, including rutile, zircon, magnetite, corundum, tourmaline, etc., are to be seen.[1]

The pebbles are mostly of a transparent, white, or smoky character, while more rarely some have the appearance of chalcedony, jasper, or chert. Sometimes fragments of quartzite and slate occur in the conglomerate, but they are few as compared with the quartz pebbles. In some places it is found that the coarser the pebbles, the richer the conglomerate in gold, but this does not always hold good, and sometimes the finer conglomerates are the richer. All the Witwatersrand ores are more or less impregnated with iron sulphides, pyrite

[1] Hatch and Corstorphine, *op. cit.*, p. 136.

and marcasite, which vary somewhat in amount in different places. Though the sulphides are usually abundant where the ore is rich in gold, yet they are also often abundant where the ore carries very little gold, so that the quantity of them is not necessarily an indication of the richness of the ore. They are sometimes very finely disseminated in minute particles, at other times in a coarser condition, generally crystalline, and sometimes in concretionary or radiating nodules. They are generally oxidized for a few hundred feet from the surface, giving the ore a brown, rusty appearance, while at a greater depth the ore assumes a gray or greenish-gray color.

The gold is finely disseminated in the ore and is rarely noticeable to the naked eye, though it can sometimes be seen in thin flakes incrusting the pebbles, or in small particles in the siliceous matrix. The gold is not uniformly distributed through the reefs. There are rich places and poor places, but in spite of this, it may be said that the gold is much less irregular over long distances than in most gold deposits, and in no other part of the world can so many mines be seen on the same ore body.

Most of the ores mined in the Witwatersrand district are of low grade, though bodies of higher-grade ore occur, and more rarely small amounts of very rich ore are found. The value usually varies from a grade too low to work profitably up to about $25 per ton and sometimes to very much more. Under the ordinary conditions existing in the district, ore of $6 per ton is about as low-grade material as it pays to work, and most of the ore at present being treated ranges from about that value up to $12 or $15 per ton. The average value of the ore mined in the Witwatersrand district in the year ending June 30, 1905, was from 36.888 to 37.123 shillings,[1] or a little less than $9 per ton.

In the early days only the higher-grade ores were worked, but with the increased facilities for mining and milling, the cost was diminished, and the tendency is, therefore, to save the lower-grade ores which were once thrown away, and to mix them with the higher-grade ores, thus bringing down the average value of the ore treated, but adding to the aggregate amount of gold produced.

The mines vary in depth from a few feet to over 4,000 feet, quite a

[1] "Transvaal Mines Department," *Annual Report of the Government Engineer for the Year Ending June 30, 1905*, p. 8.

number ranging from 1,500 to 2,500 feet, and a few deeper. Those located on the outcrop of the ore are known as "outcrop" mines; the adjoining ones to the south, which are not on the outcrop, but which require a shaft to be sunk to reach the ore on its dip, are known as the "first row of deeps," those next farther south are known as the "second row of deeps," etc. The general term "deep" is thus applied to any of the mines not on the outcrop, and the first, second, third, and even fourth rows of deeps are common terms. The word

FIG. 6.—Photograph of surface at the Robinson and the Robinson-Deep Mines, Witwatersrand District, Transvaal, showing tailings, dumps, and general surface conditions.

"deep" does not refer in any way to the depth of the mine, but only to the fact that a shaft has to be sunk to reach the ore.

It is not within the scope of this article to discuss the metallurgical treatment of the Witwatersrand ores. It may be said, however, that nowhere else in the world have the mining and treatment of gold ores been carried on with greater efficiency and skill than by the able engineers and metallurgists who have conducted the operations on the Rand; and nowhere has the gold-mining industry been conducted on such a large scale. The ores are treated in large stamp

mills located at or near the mines (Fig. 6), and it is a striking sight to look out from some elevated place and see the long row of immense milling plants following an east and west line as far as the eye can reach along the strike of the ore formation. The ore is partly free milling. About 55 to 65 per cent. of the gold is saved on amalgamating plates, and a large part of the rest is obtained by cyaniding the tailings. Sometimes additional processes to make a more complete extraction are practiced. A well-equipped and well-managed mill, with the present methods, should make a total extraction of probably from 88 to over 90 per cent. of the gold in the ore.

The Witwatersrand district is essentially a region of large quantities of low-grade, yet workable, ore, and there are but few places in the world where gold mining can be carried on so cheaply as there. The ore bodies extend over long distances, and their contents of gold is much less erratic than in most gold mines elsewhere; coal, which is the only available fuel, is found in large quantities in close proximity to the mines, in geological formations overlying the gold-bearing rocks; Kaffir and Chinese labor is cheap, though at present somewhat scarce; the climate is healthy; the mines as a rule are not troubled with any excessive amount of water; the temperature does not increase at a very rapid rate with depth; and the rock is of such a kind that the expense for timber to hold up the underground workings is not great (Fig. 5). Under all these favorable conditions mining can be carried on to very considerable depths so long as the ore holds out, and it is probable that active mining operations will be continued in this region for many years.

The production of the Rand mines from 1884 to June 30, 1906, was over 134,000,000 pounds sterling, or somewhere about $650,000,000, which means practically almost the total production of the Witwatersrand district from the start, as not much gold was obtained there before 1884. The production for 1906, according to the estimates of the Transvaal Chamber of Mines, was 24,579,987 pounds sterling.[1]

It is not intended in the present article to discuss the origin of the Witwatersrand gold ores in detail, but perhaps a few words about the generally accepted ideas on this subject may be well.

[1] These figures for 1906 were kindly furnished to the writer by Mr. W. R. Ingalls, editor of the *Engineering and Mining Journal*, of New York.

The origin of the conglomerates themselves, without reference to the gold in them, was doubtless similar to that of many other conglomerates elsewhere, that is, they were formed by the accumulation of gravel and sand under water near shore. It is probable that they are of marine origin and were laid down along the shore line of some more or less open sea. Later on they were covered by other strata, then elevated into a land area, folded and distorted by the dynamic action to which the region has been subjected, then more or less eroded by atmospheric influences, and eventually left as they are now found.

As to the source of the gold in the conglomerates, there has been much more dispute than as to how the latter were formed. Two different theories, among the several that have been advanced on this subject, seem to have received most support. One of them supposes that the gold is all detrital, that it was deposited mechanically with the pebbles of the conglomerates at the same time as these beds were formed, and that it came from the same rocks as the pebbles, or at least from adjacent rocks. In other words, this theory supposes that the gold-bearing conglomerates are simply old placer deposits. The second theory supposes that the gold was brought into the conglomerates after the latter had been formed and probably after they had been elevated into land areas, that the conglomerates simply acted as pervious strata through which gold-bearing solutions found a ready passage, and in which the gold was deposited in much the same way as it is supposed to have been deposited in the fissures containing it in most gold districts.

George F. Becker[1] supports the first theory and believes that the gold was deposited mechanically with the pebbles of the conglomerates and that it came from the erosion of the same land area, though it may have been somewhat changed in position and character by subsequent chemical action. He thinks the conglomerates are of marine origin, and that they are in fact simply marine placers, solidified by the later deposition of secondary silica.

Messrs. Hatch and Corstorphine,[2] on the contrary, believe in the second theory, that is, that the gold was deposited from solutions

[1] "The Witwatersrand Banket, with Notes on Other Gold-Bearing Pudding Stones," *United States Geological Survey, Eighteenth Annual Report, 1896–7*, Part V, "Metallic Products and Coal;" pp. 173–77.

[2] *The Geology of South Africa*, pp. 145, 146.

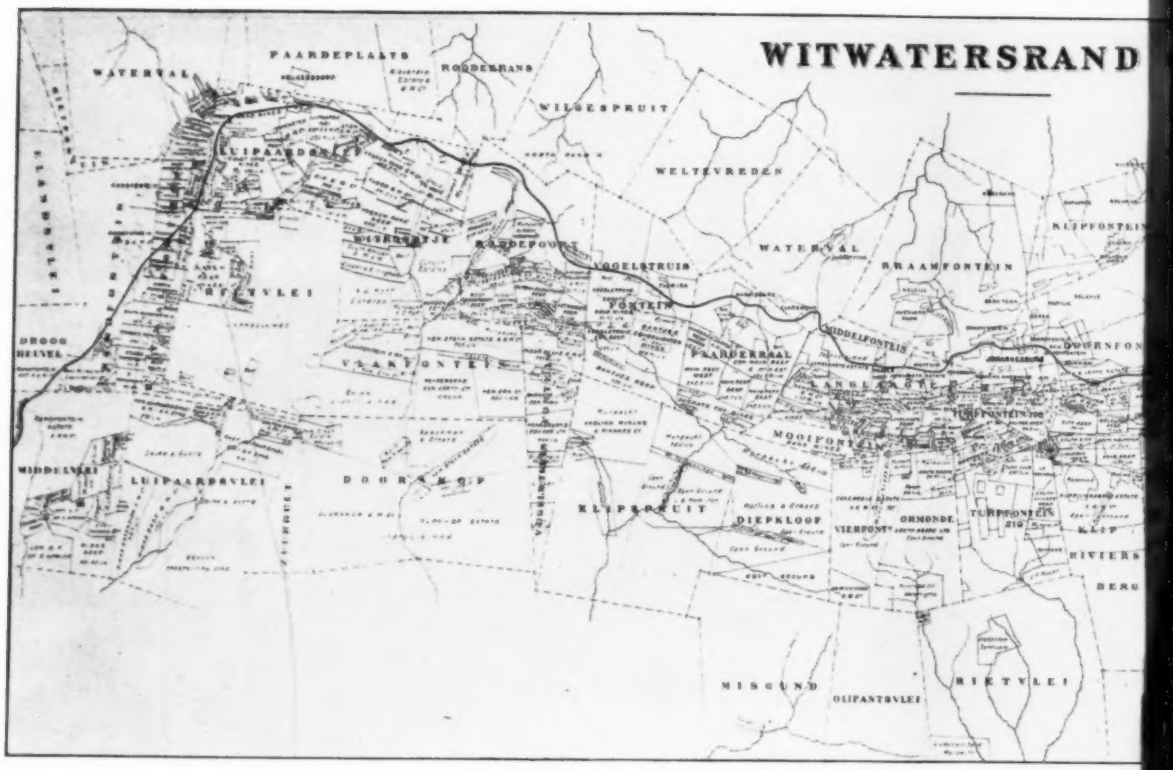
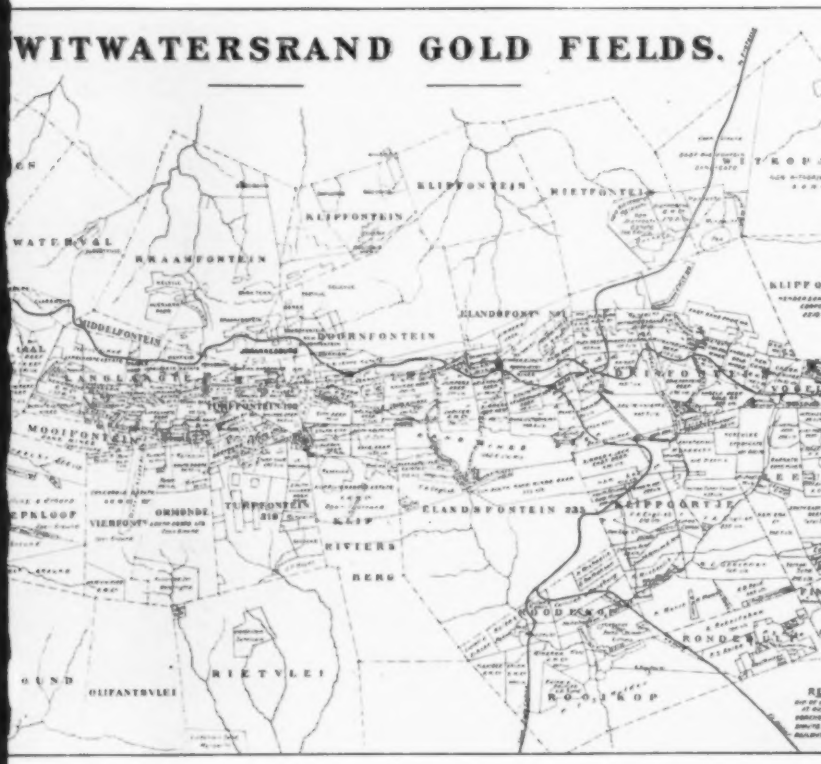
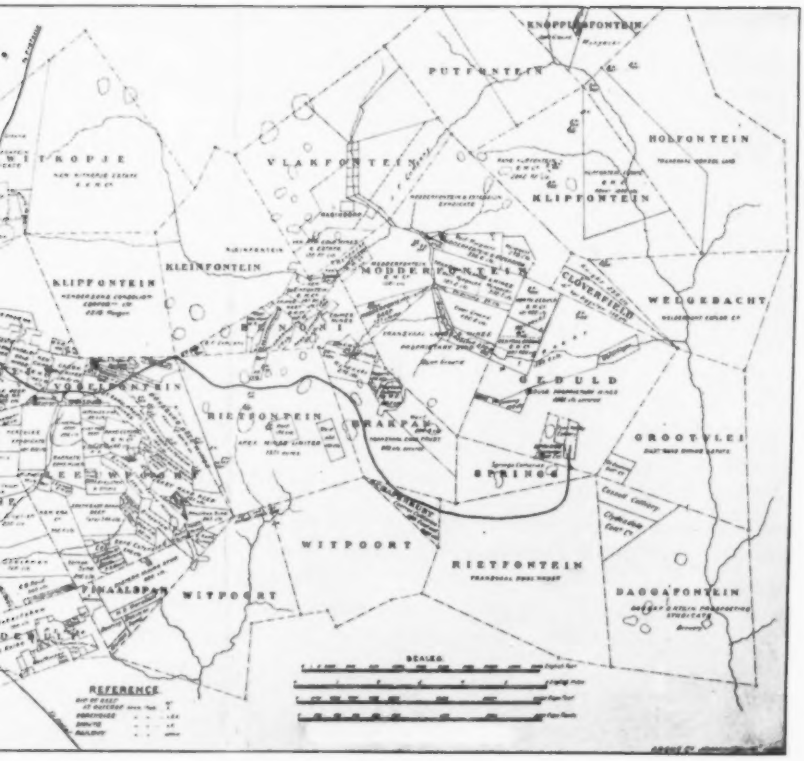


FIG. 7.—Map showing the distribution of mining



7.—Map showing the distribution of mining claims in the Witwatersrand District, Transvaal.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CLOVERFIELD
WELGEDACHT
GELDULD
RIETFONTEIN
GROOTVLEI
SPRINGS
WITPOORT
RIETFONTEIN
WITPOORT
DAGGAFONTEIN
REFERENCE
SCALES

Transvaal.

permeating through the conglomerates after their formation, in much the same manner as gold is deposited in fissures elsewhere. They think that with the gold were also deposited the pyrite, marcasite, and other secondary minerals found in the deposits, including the secondary silica, which has bound the once open pervious conglomerates into solid compact rocks. Most of the geologists and engineers who have been directly connected with the mines in the Witwatersrand district also hold more or less similar beliefs. John Hays Hammond,[1] formerly the noted engineer of the Consolidated Goldfields of South Africa, thinks that a large part of the gold got into the conglomerates in this way, but that some of it was also deposited originally with the conglomerates.

W. H. Penning[2] and L. DeLaunay[3] have suggested that the conglomerates were formed in sea water which was heavily charged with gold and iron sulphide in solution, and that these were deposited in the conglomerates during their formation. This theory has not received much support from others familiar with the region.

[1] "The Genesis of the Witwatersrand Banket," being chap. vi of *The Witwatersrand Goldfields, Banket and Mining Practice*, 1898, by S. J. Truscott.

[2] *Jour. Soc. Arts*, London, Vol. XXXVI, 1888, p. 437.

[3] *Les mines d'or du Transvaal*, 1896.

METAMORPHISM BY COMBUSTION OF THE HYDROCARBONS IN THE OIL-BEARING SHALE OF CALIFORNIA[1]

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INTRODUCTION

A unique variety of metamorphism has been at work locally in many regions of bituminous rocks in California, where a process of combustion of the hydrocarbon contents has altered the naturally white, soft shale to a rock of brilliant rose or brick-red color, and rendered it in cases hard and vesicular like scoriaceous lava. The resemblance of the products to those of volcanoes and the existence of centers like solfataras where the process of burning has been going on during the last half-century, has given rise to the statement that there were living volcanic vents in Santa Barbara County. Though the combustion is usually local in its effects, the number and wide distribution of the occurrences of burnt shale lend importance to the phenomenon. The presence of burnt shale at depths varying from 90 to 1,040 feet below the surface, as discovered in the drilling of oil wells, proves that the burning has taken place deep down within the oil-bearing formation, as well as at the surface where it has been more commonly found. And further, the discovery of fragments of it at one place at a depth of at least 10 feet below the surface in bedded deposits of Pleistocene age proves that such action has gone on not alone in recent times. The present article deals with some

[1] Published by permission of the Director, U. S. Geological Survey.

typical occurrences of shale altered in this way in the region of the oil fields of Santa Barbara County.

The Monterey shale, of middle Miocene age, is the oil-bearing formation, and the process of burning has had its chief effect upon portions of this formation. It is composed almost exclusively of soft and hard, thin-bedded, siliceous shales, which are largely of diatomaceous origin (see Fig. 1).

INSTANCES IN WHICH THE SHALE IS AT PRESENT BURNING

A number of instances have been observed in which combustion is at present or has been in recent years in progress within the Monterey shale. One example is afforded on the north side of Graciosa Ridge south of the Santa Maria Valley near the Rice Ranch oil well No. 1. When this locality was visited by the writers early in the autumn of 1906 a fire was burning underground in the shale, causing a smoke of disagreeable odor to issue from the surface and making the ground hot over an area of many square yards. Oil was oozing up at various points near by, and the ground was heated in the neighborhood of all of these seepages. The holes from which vapor issued were coated with delicate crystals of sulphur. At the point where the burning was actually going on and all about in the vicinity, for a distance of several hundred feet in some directions, the shale was altered to a bright red color, or baked almost to the hardness of compact igneous rocks, or rendered vesicular like lava.

There can be no doubt that this fire was supported by the bituminous material in the shale, and its starting was probably due to brush fires. The brush round about had been burnt, but the fire had swept over it a good many months before, as shown by the new growth on the bushes. It was said that there was a brush fire about January 1, 1906, which started the fire in the shale, and that futile attempts had been made ever since that time to put out the underground fire by dumping dirt upon it in the attempt to smother it. It seems likely, however, that this same fire has been in progress for several years. This likelihood is borne out by other accounts. It is stated that sometimes during the course of brush fires on the hills sudden darts of flame may be seen at night from a considerable distance—the result of the setting on fire of gas escaping from the rocks.

Similar phenomena were mentioned[1] by Thomas Antisell half a century ago as existing in the region near the coast east of Santa Barbara, but they were regarded by him as being of a volcanic nature. Of the foothills of the Santa Ynez Mountains a few miles east of Santa Barbara, he says:

> In this part of the chain the volcanic forces can not be said to be quiescent as yet. On Dr. Robbin's ranch . . . . occasionally fire, smoke, and sulphurous vapor has been emitted, from fissures in the rock, in large quantities within a few years past. A similar volcanic vent exists at Rincon.

The fire at Rincon Point referred to above, and which went popularly by the name of the "Rincon Volcano" was still active in 1890, when the vicinity was visited by Professor H. C. Ford.[2] In the course of his description he says,

> I found hot gases bursting from numerous apertures in the shales, accompanied in some cases by melted bitumen that hardened in concretionary masses upon cooling. . . . . Crystals of sulphur had also formed upon all objects near the issue, and naptha appeared to be present. A few years ago a tunnel was run into the cliff at its base to a depth of 200 feet in search of oil. At this depth the workmen were obliged to cease operations in their endeavor to penetrate farther on account of the great heat. Upon entering this tunnel I found the temperature still high but noticed only weak sulphurous gases. Near the entrance for 50 or 60 feet the roof and sides were thickly covered with attenuated colorless crystals of epsomite hanging in tufts and masses. . . . . When the excavations of the Southern Pacific Railway were made at a point a mile farther west from the locality just described, a similar issue was discovered, and upon touching a match to the gas, combustion ensued and continued, notwithstanding vigorous efforts were made to extinguish it. . . . . During the summer of 1888, Mr. Richardson, who resides a short distance below the Rincon "fire wells," was startled by loud reports in their direction and upon visiting the locality observed flames issuing to the height of several feet from the apertures. Parties from Santa Barbara visited the spot upon hearing of this outburst and confirmed Mr. Richardson's observations.

The same writer mentions a similar "solfatara" on the San Marcos Ranch in the Santa Ynez Valley, and says, "Distributed over the surface were eight or ten apertures from which rose visible sulphurous fumes to the height of from two to three feet." He found the tem-

[1] *Explorations and Surveys for the Pacific Railroad*, Vol. VII, p. 71, Washington, 1857.

[2] *Bull. Santa Barbara Soc. Nat. Hist.*, Vol. I, No. 2, October, 1890.

perature of the gases upon their issue "to be so high that the hand could not for a moment bear the heat." It is not known to the writers whether these fires are still burning.

TYPICAL OCCURRENCES OF BURNT SHALE

The Santa Maria oil district in northern Santa Barbara County is rich in outcrops of rose-colored shale and other products of the burning process, these occurring in eight or ten separate localities. The best examples are along the ridge bordering the Santa Maria Valley some eight miles southwest of Santa Maria; on the north and south sides of Graciosa Ridge, a similar distance south of that town; and on Redrock Mountain, four miles southeast of Los Alamos. In each of these regions every stage of alteration is exhibited from the slightly discolored shale to hard slag-like rocks of varying shades of red and black (see Fig. 2). The area of altered shale in the different localities varies from a small one of some hundred square feet to one of half a square mile or more, as at Redrock Mountain. They are in every case surrounded by unaltered, usually soft, white, diatomaceous shale, which in the majority of cases shows the planes of stratification (see Fig. 1). No case was observed in which a sign of stratification was left in the baked shale. In every case the shale in the neighborhood is bituminous and asphalt deposits are usually adjacent.

The largest area of altered shale in this region is on the summit and surrounding ridges of Redrock Mountain south of Los Alamos. This is the highest of the hills in the basin region between the San Rafael and Santa Ynez Mountains, being 1,968 feet above the sea, while the usual height of the summits round about is from 1,000 to 1,500 feet. It seems to owe its prominence, at least in part, to the metamorphosed shale forming its summit. In the case likewise of the 800-foot hill on the southeast side of the Southern Pacific Railroad coast line at Schumann Pass, the capping of volcanic-looking rock of this same character seems to have caused the topographic relief. The metamorphism in these cases probably took place a long time ago. At Redrock Mountain, in places in contact with the altered shale, are great deposits of asphalt and a large area of shale impregnated with bitumen.

DEPTH TO WHICH ALTERATION HAS EXTENDED

The depth to which alteration has extended below the surface in these cases is difficult to determine. A cliff of burnt shale 50 to 100 feet high is exposed 4½ miles due south of Guadalupe, and the difference of elevation of points in the Redrock Mountain neighborhood where the altered rock outcrops amounts to several hundred feet.

FIG. 1.—Hand specimen of typical diatomaceous shale from the Santa Maria oil district, Santa Barbara County, California (slightly reduced).

That such metamorphism of the shale has not been solely a surface phenomenon is shown by the fact that burnt shale has been found on drilling at considerable depths. Mr. Orcutt, of the Union Oil Company, exhibited samples of red shale, coming from depths of 950 to 1,040 feet below the surface in Hill well No. 1 in the Lompoc Field, which are identical in appearance and texture with the burnt shale elsewhere. Traces of petroleum were associated with the upper stratum of burnt shale in this instance. There are numerous wells in the Santa Maria field in which red shale, doubtless burnt, was met with at depths varying between 90 feet and 330 feet below the surface. The hardening consequent upon the burning has sometimes rendered the rock difficult to drill through.

LITHOLOGIC CHARACTER

The burnt shale exhibits all stages of change from slight induration and discolorization due probably to oxidation of iron, to extreme hardening, and partial fusion. When slightly altered the normal white shale assumes a light pink color. From this stage it passes through various shades of rose and brick red and deepens in color to

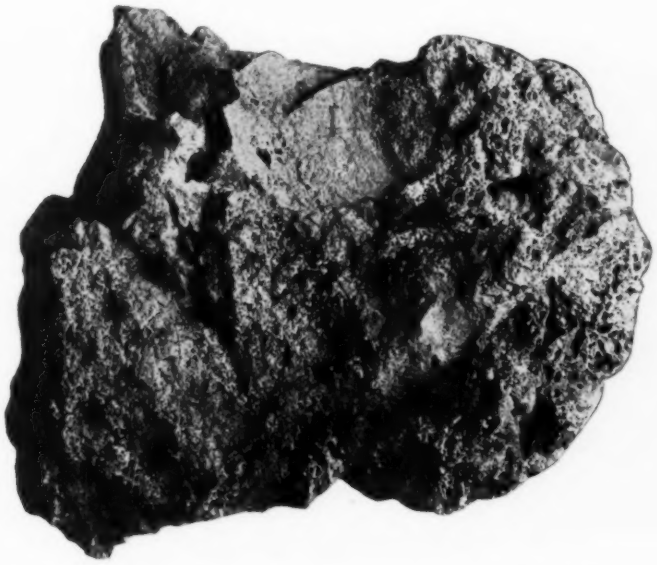

FIG. 2.—Hand specimen of a similar shale after metamorphism by burning (slightly reduced).

a reddish, bluish, or greenish black or true black. In the advanced stages of change it becomes a rough, brittle, reddish, porous slag just like vesicular lava, like that shown in Fig. 2, or a very hard, compact, dark and dull-colored rock looking somewhat like a compact igneous rock. It is not crystalline, but the texture is variable so as to give a patchy appearance to surfaces. In one place it will be compact and black, nearby full of irregular cavities surrounded by patches of different colors, or again vesicular and reddish. Whereas the weight

of the original shale is slight, the lighter varieties having a specific gravity less than that of water, the excessively burnt shale is very heavy. The material has evidently contracted to much less than its original volume, the angular cavities and irregular vesicles being one consequence of this contraction.

Under the microscope the more advanced stages appear as having an exceedingly fine-grained, amorphous, porous ground-mass discolored with a reddish brown or gray stain. Black filaments and dots appearing like carbonaceous material are common. Exceedingly minute rounded and irregular grains scattered through the whole, but forming no appreciable proportion of it, are the only portions visible under crossed nicols. They extinguish four times in a revolution of the field, and are probably clastic quartz grains. These are characteristic of the unaltered shale as well.

Mr. George H. Eldridge remarks[1] on an occurrence of burnt shale in the Santa Maria field near the old Blake asphalt mine south of Graciosa Ridge. He says, "The shale now appears red, ash-like to hard and clinker-like, glazed or silicified; bodies of bitumen contained within this have the appearance of a coke, as though derived from the solid fixed carbon of the petroleum."

The likeness of varieties of the burnt shale to volcanic rocks is indicated by the fact that Thomas Antisell in his account of the geology of the Coast Ranges in the Pacific Railroad Report,[2] describes "scoriaceous" and "amygdaloidal lava," "whitish-gray, hard trachytic rock," "volcanic," and "igneous rocks" in the region of the Santa Ynez River, evidently having reference to the burnt shale. He considered it to be in eruptive masses, forming the oldest and axial rocks of the hill ranges, whereas it is part of the Monterey shale formation which overlies the basement formations. He regarded the associated diatomaceous shales in some places, although not in others, as "magnesian" and "tremalite" rocks of igneous origin. He refers to the places where the shale is burning as examples of present volcanic activity.

[1] "The Asphalt and Bituminous Rock Deposits of the United States," *Twenty-second Annual Report, U. S. Geological Survey*, 1901, Pt. I, p. 428.

[2] *Explorations and Surveys for the Pacific Railroad*, Vol. VII, pp. 65–72. Washington, 1857.

CAUSE OF THE ALTERATION

There can be little doubt that the burnt shale is in all cases the result of heat produced by combustion of the hydro-carbon contents of the shale. The phenomenon is confined to the Monterey shale, which is the source of a large part of the California petroleum, and to those regions in which this formation is extremely bituminous. The shale in such places is frequently impregnated with petroleum and the cracks partially filled with it. The altered shale areas are almost invariably situated in the vicinity of oil seepages, which usually connote a fractured condition of the rocks such as would allow fire to spread and be supported. The observance of fires actually in progress in the shale and the changes that have taken place in the rocks round about—changes in every way similar to those in localities of the metamorphosed shale where no fire exists at present—gives the best of clues to the manner in which the shale has been baked in other cases. It is difficult to conceive of a source of heat sufficient to cause local baking of the shale in otherwise unaltered strata at a depth of 1,000 feet below the surface in such a case as has been mentioned. Probably there, as on the surface, it was due to ignition of bituminous material. It is probable that fire started in the petroliferous shale at the surface and threaded its way downward along cracks partially filled with bitumen or gaseous hydrocarbons. The failure to smother the fire in the shale on Graciosa Ridge, as previously mentioned, indicates that such fires are able to survive with a limited air supply. On the other hand if the above theory is correct it indicates that a considerable amount of oxygen may be present in the rocks at such a depth.

The cause of ignition may be kindled fires, lightning, or the spontaneous combustion of the hydrocarbons or surface vegetation. Many of the recent cases of burning are directly traceable to the first cause, but for those which may have taken place before the advent of man, either the second or third cause will have to be invoked.

Burnt shale was noticed by J. D. Whitney in the vicinity of Santa Barbara, and its origin rightly interpreted. He says of it:

> About five miles southeast of Carpinteria, the rock presents exactly the appearance of having had the bituminous matter burned out of it; it assumes various

colors, such as bright red, rose, brown, yellow, and cream color and it appears to have been partially fused in some places. [1]

And again he remarks, referring to the same region.

In some localities the rock has evidently been on fire, and the bituminous matter having been burned out—the operation continuing for several years, as it is said—the slates are left of various shades of red, produced by the oxidation of the iron.[2]

Burnt-shale areas occur in many places besides in Santa Barbara County. Mr. G. H. Eldridge[3] makes the following comment on its occurrence and origin in Ventura County where especially good examples are to be found south of the valley of the Santa Clara River on Oak Ridge and the crest of South Mountain.

The siliceous shale and "chalk rock" forming the crest of the mountains south of the Santa Clara have at many points been burned to a bright red color. The fuel which supported such fires was perhaps the originally contained petroleum.

Opposed to this view, however, is the very considerable depth to which the shale has been altered to a brilliant red lava-like rock; hence it may be inferred that spontaneous combustion alone has brought about the modification.

RANGE IN TIME OF THE PHENOMENON

As already mentioned, the marked influence of the hardened shale on the topography in certain instances points to its origin in those cases a long time since. The age of some of the burnt shale areas is further shown by the presence of numerous fragments of it at a depth of at least ten feet below the surface in horizontal beds of Pleistocene age. These beds are of sand, clay, and rough gravel, and form the low hills between Guadalupe Lake and the high hills to the west. The fragments of shale are little worn and evidently of local derivation; having very possibly come from the cliffs before mentioned south of Guadalupe. The fact that the Monterey shale underwent this kind of baking in Pleistocene times indicates further that the accumulation of the oil and its dissemination in the surface rocks took place, or was taking place, before the latest orogenic movements in this coastal region.

[1] "Geol. Survey of California," 1865, *Geology*, Vol. I, p. 126.

[2] *Ibid.*, p. 131.

[3] G. H. Eldridge and Ralph Arnold, "The Santa Clara Valley, Puente Hills and Los Angeles Oil Districts," *Bull. 309, U. S. Geol. Survey*, p. 22, 1907.

THE SUDBURY LACCOLITHIC SHEET

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INTRODUCTION

The Sudbury mining region has for nearly twenty years attracted the attention of mining engineers and geologists because of its great deposits of nickeliferous sulphides associated with a special eruptive rock. Recent field-work carried out by the writer and his assistants for the Bureau of Mines of Ontario has demonstrated that the region is even more interesting from the geological side than had been supposed; since the ore bodies form part of the edge of a great eruptive sheet having a length of 36 miles, a breadth of 16 miles, and a thickness of a mile and a quarter. While cooling this molten sheet underwent magmatic segregation in which gravitation played a large part, so that the heaviest ingredients, the ores, sank to the lowest points, merging upward into norite, the next heavier rock, which passes upward into granite, the lightest rock of the sheet.

Details of the geology of the region may be found in a final report by the writer recently distributed by the Bureau of Mines;[1] but as

[1] *Bureau of Mines* (Ontario, 1905), Part III.

many geologists do not receive these reports, it is proposed to give here a condensed account of the nickel-bearing eruptive and its general relationships to the rocks of the region.

It was quickly discovered by prospectors for nickel that all the ore deposits are associated with bands of a particular basic rock, at first called diorite, but later found to be norite. The district was mapped in 1890 by Dr. Bell, with Dr. Barlow and other assistants, and their work brought out clearly some of the features just mentioned. Two main bands of the nickel-bearing eruptive were indicated, a northern and a southern, or main, range, running with some interruptions parallel to one another in a northeasterly and southwesterly direction.[1] In 1893 a great advance was made in our knowledge of these relationships by Professor T. L. Walker, who showed that the norite associated with ore passes into micropegmatite, and also that the transition from norite to granite takes place from south to north in the main range, and in the reverse direction in the northern range.[2]

My own field-work, begun in 1902, proved that the two ranges are connected at the ends, forming an irregular oval, and as the results of three summers in the field, the upper and lower boundaries of the sheet were mapped, the only important gap occurring for about two miles at the east end, where the solid rocks are concealed by drift. This work has proved also that the sheet is basin-shaped, since the lower or basic edge everywhere dips inward; and that the ore deposits are all at the lowest points of the basic edge, showing that segregation took place by the aid of gravity.[3]

Dr. Barlow's report, which appeared in 1904, confirms these results as far as the southern range is concerned and gives an exhaustive account of the petrography of the region and the development of the nickel industry. It should be consulted by anyone interested in nickel.[4]

SHAPE AND SIZE OF THE SHEET

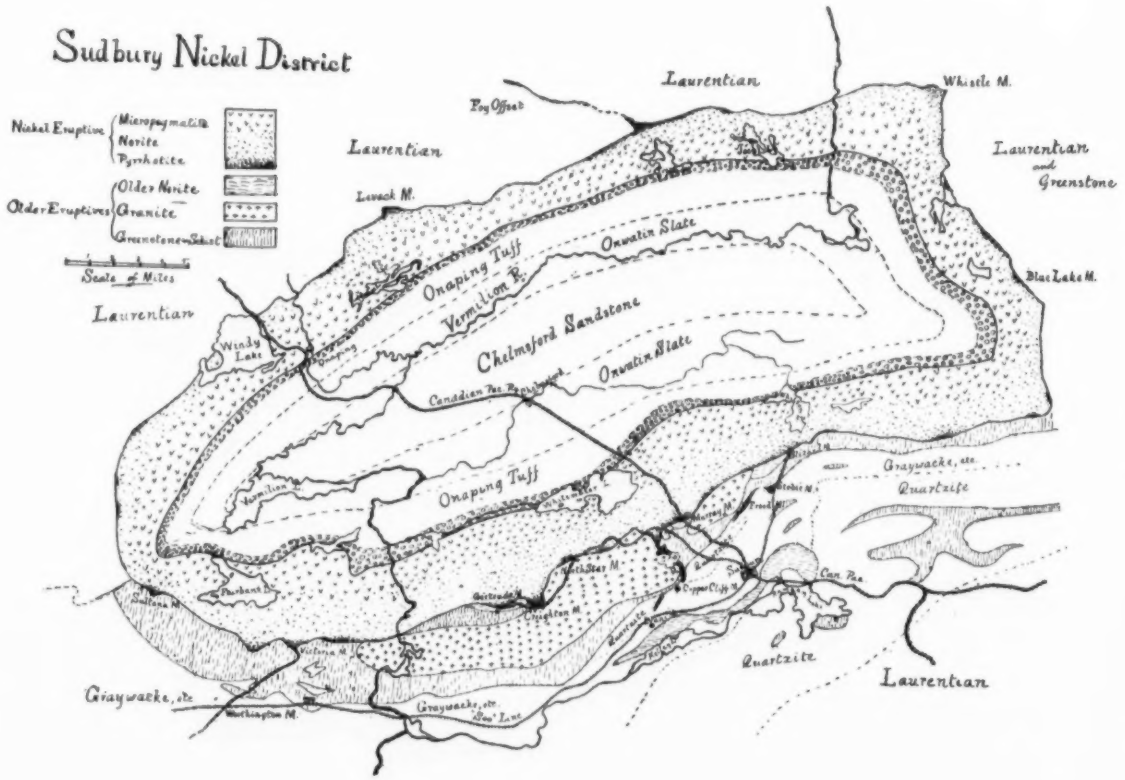
The norite micropegmatite sheet forms an irregular synclinal basin, somewhat boat-shaped or spoon-shaped, to borrow Dr. Daly's

[1] *Geological Survey of Canada*, 1890, Part F.

[2] *Quarterly Journal of the Geological Society of London*, Vol. LIII, pp. 40–46.

[3] *Bureau of Mines*, 1903, pp. 276–78, and 1904, pp. 193, 194.

[4] *Geological Survey of Canada*, 1904, Part H.


Sudbury Nickel District
Nickel Eruptives
Micropegmatite
Norite
Pyrrhotite
Older Eruptives
Older Norite
Granite
Greenstone-Schist
Scale of Miles
Laurentian
Laurentian
Laurentian
Laurentian and Greenstone
Whistle M.
Pog Offset
Levack M.
Blue Lake M.
Onaping Tuff
Onwatin Slate
Vermilion R.
Chelmsford Sandstone
Onwatin Slate
Windy Lake
Canadian Pac. Railway
Onaping Tuff
Graywacke, etc.
Quartzite
Can. Pac.
Quartzite
Laurentian
Graywacke, etc.
Graywacke, etc.
Worthington M.
Moo' Lake

apt expression, the bowl of the spoon being filled with sedimentary rocks everywhere dipping inward. It rests upon the steeply upturned edges of Huronian schists as well as on Laurentian gneiss and some eruptive masses later than the rocks just mentioned. It is evident that the sheet separates two series of rocks having entirely different attitudes, and that originally the upper sediments rested uncomformably on the lower rocks. In Dr. Daly's "Classification of Igneous Intrusive Bodies" it corresponds to an "interformational laccolith."

As will be seen from the accompanying map, the sheet has an outcrop of irregular width varying from five-sixths of a mile at the narrowest point of the northern range to four and one-fifth miles at the widest part of the main range. The average width is two miles and a half. As exposed at the various mines and prospects the basic edge dips inward, at angles from 20° to 64°; while the sedimentary rocks overlying the sheet have an average dip of about 30°.

Accepting 30° as the correct average dip, the thickness of the sheet is a mile and a quarter. The syncline is 36.2 miles long by 16.6 miles wide, with an average width of 13.6 miles; so that its solid contents must be about 600 cubic miles, if the concealed parts are as thick as the exposed edges.

The upturned edges of the sheet have no doubt undergone great erosion, since the region has been exposed to erosion since Cambrian times. If we suppose that a width of three miles has been removed all around, the original mass must have been 1,000 cubic miles. In magnitude, then, the Sudbury laccolithic sheet far surpasses even the great sills described by Dr. Daly from British Columbia.

As the term "sill" seems to imply a flat-sided body rather than a curved one, and as sills regularly lie between two layers of sedimentary rock, I have preferred the non-committal term "sheet" for the Sudbury eruptive, which is synclinal and rests on a somewhat irregular surface made up of a complex of schistose and eruptive rocks.

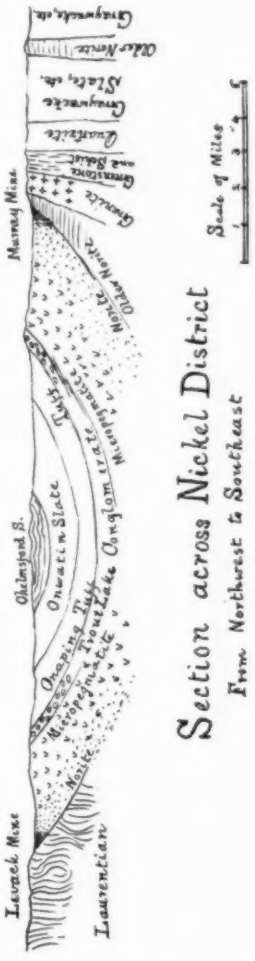
CAUSE OF THE SYNCLINAL FORM

One naturally asks why the eruptive sheet with the overlying sedimentary series should form a synclinal basin. As the surrounding and underlying rocks show hardly any sympathy with this synclinal arrangement, we cannot assume that it is due to lateral mountain

building thrusts, but must look for some other cause. The most probable supposition is that the source of the magma was immediately beneath the longer axis of the area, which is now basin-shaped, but was then flat and undisturbed.

The original molten mass was probably much thicker, but also much narrower, than the present laccolithic sheet. When it ascended and spread out widely between the upper sediments and the less regular rocks beneath, there was a collapse, since the schists and older eruptives below had lost their central support. This shows itself very plainly in the shattered and faulted character of the rocks underlying the sheet. The collapse gave rise to the roughly synclinal basin occupied by the eruptive, while the overlying sedimentary rocks settling into the still plastic magma beneath formed a more regular syncline.

The process of collapse and adjustment was probably a very slow one, beginning with the earlier upward movements of the magma, and ending only when the whole mass had cooled so far as to lose its plasticity.



PETROGRAPHY OF THE NICKEL ERUPTIVE

The petrography of this great sheet has been touched on by numerous writers, particularly since Baron von Foullon proved that the fresh rock associated with the nickel ore contains hypersthene instead of hornblende, and is therefore norite and not diorite, as it was named at first. Details of the petrography may be found in

Professor Walker's paper[1] and the reports of Dr. Barlow[2] and the present writer on the nickel region;[3] so that it will be unnecessary to give an elaborate account of the various sections made across the edge of the sheet. In general it may be said that where the outcrop is broad, as near the Creighton and Murray mines, the norite makes up about half of the section; but where the outcrop is narrow, as at some parts of the northern range, the basic portion may be nearly absent. The micropegmatite forming the upper portion of the sheet is more nearly uniform in thickness than the norite beneath The ore deposits, consisting chiefly of pyrrhotite with a comparatively small amount of pentlandite, the real nickel-bearing mineral, and chalcopyrite, are clearly parts of the eruptive and may be looked on as excessively basic phases of the lower edge of the sheet. The ore is not continuous around the whole margin, however, but occupies especially the lowest points, where the outcrop of the eruptive is wide; being largely or entirely absent from narrow parts.

In crossing a wide outcrop of the eruptive, as at the Creighton or the Murray mine on the southern range, one finds on the southeast side massive pyrrhotite resting against granite or lower Huronian rocks and more or less penetrating them as veinlets, or inclosing fragments of them. Even the massive ore contains small portions of the norite minerals, especially labradorite; and a few feet or yards to the northwest the silicates increase in quantity until, when there are about equal amounts of silicates and sulphides, the rock may be called pyrrhotite-norite. Beyond this the sulphides diminish, until within one or two hundred feet there are only blebs of pyrrhotite scattered through the norite; and at length norite without sulphides. From this point for a mile or two northwest the norite undergoes little change, then becomes reddish in color, merging into micropegmatite, which does not vary greatly till the acid edge is reached.

On narrow parts of the northern range true norite is almost absent, and an intermediate rock containing some quartz, orthoclase, and pegmatite forms the bottom of the sheet.

The norite of the basic edge of the eruptive varies considerably

[1] *Quarterly Journal of the Geological Society of London*, Vol. LIII, pp. 40–46.

[2] *Geological Survey of Canada*, Vol. XIV, Part H, 1904.

[3] *Bureau of Mines*, Ontario, Vol. XIV, Part III, 1905.

from point to point even along the broader parts of the range, but it will be sufficient for our purpose to describe the characters of an average fresh example. It should be remarked that fresh norite is oftenest found close to large ore bodies and may be shotted with particles of ore. On the southern range the rock is dark gray, coarse-grained, with blebs of bluish quartz and large flakes of biotite. On the northern range it is lighter gray, but does not differ in composition.

In thin sections the rock is found to contain labradorite to the extent of at least one-half—often more—hypersthene about a quarter, and smaller amounts of monoclinic pyroxene, hornblende, and biotite, with quartz, titaniferous magnetite, apatite, and often sulphides as accessory minerals. The labradorite is usually very fresh, pale brown from dusty inclusions on the southern range, and clear on the northern, with hypidiomorphic forms, sometimes platy. The hypersthene forms rough prisms with good pleochroism, but without scale-like inclusions. The monoclinic pyroxene seems closely related to the hypersthene in appearance, is pleochroic, but has a small or fairly large extinction angle. One is tempted to think of the hypersthene as merely augite with the extinction angle reduced to zero.

Of the minor minerals hornblende occurs mostly as secondary rims about the pyroxenes, while quartz forms small wedges between the feldspars, and occasionally has pegmatitic intergrowths with feldspar.

The typical rock just described is not found everywhere, since usually the ferromagnesian minerals are completely changed to bastite or hornblende accounting for the older designation of the rock as diorite.

At the Creighton mine the norite contains notable amounts of quartz, orthoclase, and microcline, partly intergrown as micropegmatite, but this is unusual. The country rock at this point is gneiss, in general free from micropegmatite, but sometimes showing a rim of coarse pegmatite against the norite, suggesting that the basic magma has interacted with the neighboring rock, perhaps absorbing part of it.

Thin sections of the pyrrhotite-norite found adjoining the ore bodies are often surprisingly fresh, in several of the two dozen slices

made, even the hypersthene showing little or no trace of rearrangement. The association of the pyrrhotite and chalcopyrite with the ordinary rock-forming minerals is a matter of some interest, so that the relationships of the two kinds of material in the freshest sections will be described.

The pyrrhotite and chalcopyrite occur generally together, the first being the more common of the two, and they often form sharp-edged masses of a round or angular shape completely inclosed in silicates. They most commonly accompany biotite, which may form a fringe around them, but are rather often found in hypersthene also. In many cases the sulphides lie beside solid portions of magnetite, and in one slide magnetite incloses pyrrhotite.

In the freshest sections there is no hint of a splitting-up or decomposition of the silicates inclosing sulphides, and no visible channel by which the sulphides could arrive at their present position. The edges of the hypersthene prisms are often as square and sharp against pyrrhotite as against any of the silicates of the rock, and the whole appearance suggests a nearly contemporaneous origin of sulphides, oxides, and silicates, the more basic minerals generally keeping together.

In the dikelike offsets from the basic edge of the sheet norite and ore are found mixed, the rock having the same general character as the main range, though finer-grained and more greatly weathered.

The intermediate stages between norite and micropegmatite consist of mixtures of the constituents of the two rocks, but the hypersthene is generally replaced by hornblende.

The acid phase of the sheet is quite variable, but always contains intergrowths of quartz and feldspar. The feldspars include orthoclase and also plagioclases such as andesine, while the dark minerals are hornblende, biotite, and some magnetite, but no pyrrhotite. The micropegmatitic structure ranges from very coarse intergrowths to almost submicroscopic varieties, where a small, sharply outlined crystal of andesine is inclosed in a wide border of plumy intergrowths in which the character of the feldspar cannot be determined even by high powers of the microscope. The feldspars of the acid edge are often platy, giving a hint of trachytic structure, as, for instance, near Onaping. In other cases the rock is more granitoid-looking;

but there are examples near each end of the basin where squeezing and shearing have gone so far as to produce schists. As these are often greenish in color and quite unlike granite or gneiss, they proved very puzzling in the field, but the microscope shows that they consist mainly of plumy micropegmatite with a little chlorite, and an analysis gives a composition similar to the granitic portions of the acid edge, as may be seen from column nine of the table of analyses on a later page.

Judging from its mineralogical composition, most of the acid portion of the eruptive sheet is grano-diorite, but parts of it have so little plagioclase that they might be called granite, while other parts with comparatively little potash feldspar might be called quartz-diorite.

RELATION OF THE BASIC EDGE TO THE ROCKS BELOW

As may be seen from the map, the basic edge of the laccolithic sheet is, in places, quite irregular, with inward projections of the country rock and bays directed outward. From some of the funnel-shaped bays narrow bands of norite reach out into the country rock, sometimes for several miles, but usually with gaps in their continuity. For these projections I have used the term "offset" rather than "dike," since the latter implies a continuous sheet of eruptive rock with somewhat uniform width. One or two of these offsets may be described to bring out the relations of the nickel eruptive to the rocks on which it rests.

Where the country rock extends like a promontory into the basic edge there are no ore bodies, but where the opposite occurs, the norite pushing baylike into the country rock, as at Creighton, large ore bodies are found. When such a bay opens outward into an offset, as at Copper Cliff, the ore forms only small deposits along the sides of the funnel, but larger bodies where interruptions break the offset. In the Copper Cliff offset, for example, we find first a wide bay, with three small masses of ore along its edges; then a narrow band extends southeast for a third of a mile, ending in No. 2 mine, a body of ore 230 feet in length along the offset, and half as wide. This chimney-like deposit has been worked to a depth of 400 feet, and probably goes much deeper.

To the south of this the offset is cut off for a third of a mile, but reappears at the famous Copper Cliff mine, with an ore body 75 to 200

feet in length along the offset and 50 to 90 feet across it, and having a known depth of 1,000 feet. About 700 yards west there is a narrow band of norite with some ore running south for about a quarter of a mile. After another gap of two-thirds of a mile the last outcrop of norite and ore occurs at the Evans mine. The whole length of the offset is more than 4 miles.

It is assumed that all the isolated stretches of norite and ore are either connected by devious channels below the surface, or that they were once connected by portions that have now been eroded away.

One band of norite and ore, that of the Frood and Stobie mines, is of a different kind, showing no point of attachment with the basic edge of the eruptive, but running for 2 miles nearly parallel with it. Here there is probably an underground connection with the main range. The longest offset is from the middle of the northern range, running more than 6 miles to the west.

The basic edge of the nickel eruptive has often a very irregular contact with the rock beneath, frequently inclosing blocks of it and running short distances into it. The offsets are variable in cross-section, and sometimes form curious breccias with blocks of the adjoining rocks, and also of norite of a coarser or finer grain than the matrix. The pyrrhotite takes its part in these relationships very much as the rock does, but it probably remained fluid longer than the norite and has penetrated more intricately into the rock beneath. Often both norite and rock grow finer-grained at the edge, showing that the adjoining rock was colder and chilled the magma in contact with it.

The injection of the magma between the flat-lying upper rocks and the complex of graywacke, schist, and granite beneath occasioned great fracturing and crushing along the lower surface, and in some cases near the southern range there are numerous faults due to the collapse of the rock-floor when no longer supported by the magma which had risen from beneath it. These irregular fractures and faults probably afforded the channels through which the offsets reached their present position.

THE UPPER CONTACT OF THE LACCOLITHIC SHEET

The acid or upper edge of the sheet seems to have caused much less fracturing and fissuring of the rocks in contact with it than the

lower edge; but, on the other hand, has exerted a far greater metamorphic action. No long dikes or apophyses are known to project from the acid edge into the overlying rocks, though some short ones have been observed.

The rocks above the laccolithic sheet are the Trout Lake conglomerate with an estimated thickness of 450 feet, the Onaping tuff, 3,800 feet thick, the Onwatin slate, 3,700 feet thick, and the Chelmsford sandstone, 350 feet thick, giving a total of 8,300 feet of sediments.

The lowest of these formations, the Trout Lake conglomerate, which was in direct contact with the upper surface of the molten sheet, has been strongly metamorphosed; and about half of the next higher one, the Onaping tuff, has been greatly indurated and silicified, though its fragmental character is still distinct. The overlying sediments are comparatively soft and unchanged, having a very modern look; while the Trout Lake conglomerate has been so metamorphosed in many places as to suggest a Laurentian gneiss, and was in fact so mapped in earlier days.

The three upper formations are fairly uniform in thickness, but the Trout Lake conglomerate varies from more than 600 feet to only 20 feet, partly perhaps because of original differences in thickness natural to so coarse-textured a rock as a bowlder conglomerate, but partly also, it is believed, because unequal amounts have been absorbed by the underlying eruptive.

The lower part of the conglomerate has been so completely reconstructed that little can be said as to its original composition except that it inclosed large and small bowlders of granite, and that the matrix had a composition which could be transformed into gneiss.

In less altered parts well-rounded pebbles and bowlders of granite, of quartzite, and of green schist or greenstone are found in a grayish crystalline matrix. Occasionally white quartzite is interbedded with the conglomerate.

The exact boundary of the micropegmatite against the conglomerate is very hard to trace. Often in our field-work when crossing the edge of the eruptive toward the sediments, we would overrun the limit, which could be recognized only by the coarser-textured and redder patches representing granite bowlders.

Thin sections made of hand specimens taken across the boundary

show first the characteristic micropegmatite of the eruptive itself, afterward changing into micropegmatite of a somewhat ruder kind in the matrix of the conglomerate. Near Moose Lake, for example, on the inner edge of the northern range the micropegmatitic character of the matrix continued for 150 paces from the edge, but had disappeared in the specimen from 180 paces. The conglomerate has been so completely transfused and recrystallized as to be easily taken for an eruptive rock containing some coarser patches, and one can properly call the relation one of gradual transition from the eruptive to the conglomerate.

CHEMICAL COMPOSITION OF THE SHEET

From the microscopic characters of the basic and acid phases of the laccolithic sheet given on a former page it will be anticipated that the chemical composition must vary greatly. These variations were first demonstrated by Professor Walker in his paper on the region, and his analyses will be quoted here with the addition of several made for the Bureau of Mines. In the table given below analyses 1 to 4 are from near the basic edge, 5 and 6 from intermediate points, and 7 to 10 from near the acid edge.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
SiO_2	49.90	51.52	56.89	60.15	64.85	68.48	61.93	67.76	68.95	69.27
Al_2O_3	16.32	19.77	19.39	18.23	11.44	12.70	13.03	14.00	12.74	12.56
Fe_2O_3	.....	.47	.38	1.51	2.94	2.41	.56	.....	.46	2.89
FeO	13.54	6.77	7.11	6.04	6.02	4.50	8.00	5.18	5.15	4.51
MgO	6.22	6.49	2.11	3.22	1.60	.74	1.76	1.00	1.57	.91
CaO	6.58	8.16	8.11	4.01	3.49	1.41	4.02	4.28	1.72	1.44
Na_2O	1.82	2.66	3.31	1.28	3.92	3.72	3.18	5.22	3.80	3.12
K_2O	2.25	.70	1.04	1.68	3.02	3.36	2.80	1.19	3.28	3.05
H_2O	.76	1.68	1.35	.55	.78	1.13	1.95	1.01	1.50	.76
TiO_2	1.47	1.39	.43	1.34	.....	.61	.84	.46	.43	.78
P_2O_5	.17	.10	.11	.23	.24	.20	.32	.19	.20	.06
MnO	trace	trace	.30	.29	trace	.05	.18	trace	.13	trace
BaO	.....	.....	.....	.25	.....	.....	trace	.....	trace	.....
SrO	.....	.....	.....	.14	.....	.....	.....	.....	.....	.....
NiO	.....	.....	.....	.17	.....	.....	.....	.....	.....	.....
Cu	.....	.....	.....	.16	.....	.....	.....	.....	.....	.....
S	.....	.....	.....	.54	.....	.....	.....	.....	.....	.....
Total	99.03	99.71	100.53	99.79	98.30	99.31	98.76	100.20	99.93	99.35
Specific gravity	3.026	2.832	2.834	.....	2.788	2.673	2.757	2.709	2.694	2.724

In the above table No. 1 and No. 2 are from the basic edge of the southern range near Blezard mine; analyst, Professor T. L. Walker. No. 3 is from the basic edge of the northern range near Onaping; analyst, Mr. E. G. R. Ardagh. No. 4 is from the Creighton mine near the ore body; analyst, Mr. M. T. Culbert. No. 6 is of a syenitic-looking specimen from near the middle of the Onaping section; analyst, Mr. Ardagh; and No. 7 is by the same gentleman, of a greenish-gray specimen from the acid edge at Onaping. No. 8 is from near the acid edge of the Blezard-Whitson lake section; analyst, Professor Walker. No. 9 is from the acid edge on the north shore of Fairbank Lake in the southern range, the rock being dark green-gray and somewhat schistose; analyst, Mr. Ardagh. No. 10 is from near the acid edge of the Blezard-Whitson lake section; analyst, Mr. C. B. Fox.

It should be mentioned that No. 4, from the Creighton mine, is exceptional for the basic edge, containing considerable quartz, microcline, and micropegmatite, perhaps absorbed from the adjoining granitoid gneiss.

The two analyses of specimens taken about half-way between the basic and acid sides of the sheet do not differ greatly in composition from analyses of rock from the acid edge itself, and must be looked on as really belonging to the micropegmatitic side of the eruptive. Averaging the first four analyses as representing the norite, and the last six as representing the micropegmatite, we get the following results:

	Basic Average	Acid Average	Total Average
SiO_2	54.615	66.873	61.970
Al_2O_3	18.437	12.745	15.022
Fe_2O_3	.500	1.543	1.362
FeO	8.365	5.562	6.683
MgO	4.510	1.263	2.542
CaO	6.715	2.727	4.322
Na_2O	2.267	3.827	3.203
K_2O	1.417	2.787	2.239
H_2O	1.085	1.188	1.147
TiO_2	1.157	.502	.763
P_2O_5	.152	.202	.182
MnO	.122	.060	.065
Minor substances	.320	.....	.....
Total	99.752	99.279	99.500

The total average was obtained on the basis of two parts basic rock to three parts of acid rock, which corresponds roughly to the field relations. The ore deposits, really integral parts of the basic edge, have been left out in the calculation, since the percentage which they form of the whole eruptive is relatively small, though about 2,500,000 tons of ore have already been mined and many millions more are known to exist. Professor Vogt refers to the Sudbury gabbro as containing originally about 0.05 per cent. of the ore, which may serve as a not improbable guess at the quantitative relations.

According to the new classification of eruptive rocks, the average basic side of the eruptive may be called Harzose, and the acid side Adamellose. The norm for the two phases is as follows:

	Basic		Acid	
Quartz	9.24		20.76	
Orthoclase	8.34		22.24	
Albite	19.39	51.92	31.06	37.73
Anorthite	32.53		6.67	
Diopside $CaO \cdot SiO_2$	.....		2.44	
Diopside $MgO \cdot SiO_2$	.....		.70	3.99
Diopside $FeO \cdot SiO_2$	.....		.85	
Hypersthene $MgO \cdot SiO_2$	11.30	24.10	2.40	8.74
Hypersthene $FeO\ SiO_2$	12.80		6.34	

The norm of the rocks as worked out above, omitting minor ingredients, corresponds fairly well with the mode in the norite of the basic side, except that monoclinic augite replaces some of the hypersthene. In the average acid phase of the eruptive pyroxenes hardly occur, being replaced by hornblende and biotite.

CAUSES OF THE DIFFERENTIATION

In my report on the Sudbury nickel region it was suggested that the differentiation of the ore from the rock, and of the norite from the micropegmatite, is mainly due to gravitation. The sulphides are of course far heavier than norite, and the norite is heavier than the micropegmatite; though in the latter case the difference in specific gravity is not so striking. When one observes how the ore has constantly accumulated in the hollows of the floor on which the norite rested, penetrating all the fissures of the rocks beneath, the conclusion seems irresistible that gravity played the main part in its segregation.

There are no ore bodies and hardly any smaller aggregations of ore in the norite above the basal edge; all have settled to the bottom.

The gravitational segregation of rather acid norite from rather basic micropegmatite seems to me on reflection not so certain, though the factor of time is in favor of it. The sediments above the eruptive sheet, without allowing for later erosion, formed a blanket 8,300 feet thick above the molten rock, and the vast mass of the sheet itself, more than 6,500 feet in thickness, must have conduced to excessively slow cooling. There are no certain means of estimating the original temperature nor the rate of cooling; but that the magma was very fluid when it spread out at first is shown by the way it has penetrated all the devious passages of the offsets described on a former page. During the hundreds of thousands of years required for cooling under the conditions mentioned there was time for even slow movements of segregation to accomplish great results.

On the other hand, the theory of stoping should be considered. At the time the field-work was done in the Sudbury region my attention had not been called to this mode of accounting for the micropegmatite, and no observations were made to test its applicability; but the analogous occurrences described by Dr. Daly in southern British Columbia, and his interpretation of Professor Bailey's observations at Pigeon Point on Lake Superior are very suggestive.[1] I have seen no direct evidence of stoping on a large scale from the overlying conglomerate, but have little doubt that the process was to some extent a factor in producing the micropegmatite. The very unequal thickness of the Trout Lake conglomerate from point to point may perhaps be accounted for by unequal stoping.

The peculiar features of the contact, where the boundary between the eruptive and the sediment vanishes, so that there is a real transition between the two, seem better explained by penetration and progressive solution of the conglomerate by the eruptive. It is quite possible, however, that at first much of the conglomerate was stoped away in blocks, sinking deep into the magma and becoming com-

[1] *American Journal of Science*, Vol. XV (1903), pp. 269 ff.; "The Okanagan Composite Batholith," *Bulletin of the Geological Society of America*, Vol. XVII, pp. 329 ff.; "Differentiation of a Secondary Magma through Gravitative Adjustment," Sonder-Abdruck aus der *Festschrift zum siebzigsten Geburtstage von Harry Rosenbusch*.

pletely digested, while later the eruptive became too viscid to allow blocks to sink, but worked on the overlying rock by heated vapors or solutions, causing the remarkable blending of the eruptive with the conglomerate. As the rock above became heated it would lose in specific gravity, until ultimately it might not have sufficient weight to sink into the magma, which was all the time growing cooler and heavier.

Another factor which may be of importance is the gradual change in composition of the upper part of the magma as it absorbed materials richer in silica, whether by digestion of sunken blocks stoped from above, or by direct solution of overlying rocks. It is well known that the more siliceous lavas are much less fluid when near their melting-point than basic lavas, so that the upper part of the sheet may be supposed to have become less and less fluid until blocks could no longer sink through the viscid mass.

It may be that all three processes took part in the differentiation of the eruptive, and that magmatic segregation and the rising of the more acid portions proceeded along with the stoping of blocks and the direct absorption of the overlying rocks.

It is worthy of remark that the micropegmatitic structure is found only in connection with the nickel eruptive; the other acid eruptives of the region are quite free from it. Can it be that micropegmatite is a structure specially belonging to rocks where basic magmas have stoped down and digested or otherwise absorbed more acid rocks? Dr. Daly's sills and the Pigeon Point rocks seem to support this as well as the Sudbury sheet.

EARLIER AND LATER DERIVATIVES OF THE MAGMA

Basic norite.—Though the nickel-bearing eruptive is by far the most important mass of igneous rock in the region, there are several other eruptives that appear to have split off from the same magma at earlier or later times, and these may be more briefly described. They include an older norite which very frequently underlies the nickel-bearing norite, though of a very different type; and certain granites which are intimately associated with the laccolithic sheet.

From point to point for several miles along the southern edge of the main range there is a complex mass of fine-grained norite and

greenstone, often with "pillow structure" and amygdaloidal phases, suggesting surface lava flows, which seems to have been an early eruption from the hearth of the nickel-bearing rock. It is, however, far more basic, containing no quartz nor micropegmatite. It is often quite fresh and in thin sections is found to consist of hypersthene or enstatite, a monoclinic pyroxene, plagioclase (bytownite), and magnetite in small equidimensional grains or imperfect crystals. Here again the monoclinic pyroxene is often pleochroic, and all varieties occur linking the monoclinic to the orthorhombic form. The two pyroxenes make up, as a rule, more than half the section, and the magnetite perhaps a twentieth, the rest consisting of short, stout crystals of plagioclase, with two or only a few twin lamellae.

An analysis by Mr. J. A. Horton shows the following results:

SiO_2	46.69
Al_2O_3	14.23
Fe_2O_3	2.00
FeO	12.86
MnO	.11
MgO	8.15
CaO	13.32
Na_2O	.98
P_2O_5	.19
TiO_2	1.28
Moisture	.08
Sulphur	.12
Total	99.97
Specific gravity	3.24

This corresponds normally to the following mineral composition:

Bytownite	42.57
Diopside	25.73
Hypersthene	20.76
Olivine	5.34
Titanic iron ore	4.98
Apatite	.34
Pyrite	.27

It is a percalcic rock of the order Gallare, class Salfemane, subclass Salfemone, and may be named Kedebekase.

It is rather curious that pyrite and not pyrrhotite is found in the older norite, which comes closer to the European nickel-bearing norites than the Sudbury nickel eruptive in chemical composition.

Granite.—Varieties of granite, and granitoid gneiss occur in bands along the southern nickel range or at no great distance from it, and are probably connected with the nickel eruptive in origin, representing a very acid phase in contrast with the very basic norite referred to above. The granites, which should not be confounded with the much older granite and gneiss of the Laurentian, are of two kinds, one coarse-grained and porphyritic, the other medium-grained; and apparently of two ages, the coarser variety being generally older than the nickel eruptive, while the finer-grained variety is distinctly younger, since it sometimes penetrates the norite as dikes or irregularly shaped bodies. The oldest of these granites is later in age than the basic norite, since it has carried off masses of it or of greenstones formed from it.

These acid rocks are normal granites with much quartz and microcline, some microperthite and orthoclase, a little oligoclase, a small amount of biotite, and still less muscovite. No micropegmatite has been found in thin sections of these rocks, a point of contrast with the granite of the acid edge of the nickel eruptive. These granites may have been split off from the general hearth by magmatic segregation without stoping or absorption of more acid materials.

An analysis of one of the later, finer-grained granites by Mr. James Horton gives the following results:

SiO_2	75.62
Al_2O_3	11.02
Fe_2O_3	3.17
FeO	1.29
MnO	.12
MgO	.26
CaO	.58
K_2O	5.33
Na_2O	3.11
TiO_2	.16
H_2O	.10
Total	100.76
Specific gravity	2.59

Calculating the normal minerals we find:

Quartz	35.76
Orthoclase	31.14
Albite	26.20
Anorthite	5.06
Hypersthene	.62
Ferric oxide	.63

Probably some of the soda belongs to the orthoclase, since the extinction angles of the plagioclase correspond to oligoclase. According to the new system the rock may be called Omeoze, a dopotassic, peralkalic rock belonging to the order Brittanare, near the boundary of Columbare.

The basic norite and the acid granites just described are thought to have sprung from the original nickel-bearing magma, because they follow so closely the southern edge of the main nickel range; but it must be admitted that they bear little resemblance to the basic and acid phases of the nickel eruptive itself.

The Ramsay Lake gabbro band.—There are, however, a few bands of gabbro which have some points of likeness to the nickel-bearing norite, though they do not occur in close connection with it. The most notable runs for 9 miles parallel to the southern nickel range as a chain of hills separated from it by 3 or 4 miles of Huronian sediments and earlier or later eruptives.

This irregular band of gabbro has pushed up and sometimes partly overturned the stratified Huronian graywacke around its margin, and a few strips of the Huronian run up its flanks at the widest part, suggesting a chain of elongated laccoliths, or possibly the blunt edge of an eruptive sheet having a nearly vertical attitude. As the gabbro differs markedly from the nickel-bearing norite, it is believed that there is no direct connection between them, but that the southern band probably split off from the magma before the main sheet occupied its present position.

The rock is medium- to coarse-grained and usually greatly weathered, though occasionally fresh enough to show its original composition of labradorite, making up about half the sections, diallage and enstatite, the rhombic pyroxene being in somewhat smaller amounts than the monoclinic. There is a very little quartz in interstices

between the plagioclase, and rarely a little micropegmatite. A small amount of pyrrhotite is found at two or three points along the band, but inclosed within the rock, not at one edge as in the main range.

The most interesting feature of this gabbro band is the great white masses of a much more acid rock which are found irregularly along the top of the ridges east of Sudbury and south of Copper Cliff. Some of these masses are 100 yards across and make a very striking contrast with the general green-gray gabbro. They are always inclosed in a margin of very coarse, dark-green hornblende, followed by a zone of mixed hornblende and white feldspar in anhedra several inches across. This phase is succeeded by a zone of white binary granite showing coarse pegmatitic structure, inclosing a central area of almost pure quartz, which may be 50 feet wide.

The hornblende often forms long prisms with a core of white feldspar. The feldspars are oligoclase approaching albite, and orthoclase (or an unstriated plagioclase), and the quartz is glassy, like vein quartz. It is possible that these curious masses, so much richer in silica and alkalies than the rest of the rock, are segregations of the magma separated from the more basic parts somewhat like pegmatite dikes in granite; but they are more probably products of the digestion of large blocks of Huronian quartzite stoped from above. They occur always on the highest points of the gabbro hills.

Very much smaller and less striking masses of a similar kind are found on the basic edge of the main nickel range near Murray mine, close to the bottom of the laccolithic sheet. This fact and the small amounts of pyrrhotite found in the gabbro band just described suggest a relationship between the two rocks. It may be that this gabbro originated in the nickel-bearing magma before segregation had advanced very far, long before the great sheet was injected into its present position.

The three types of rock described above as probably products of differentiation of the main magma, basic norite, acid granite, and intermediate gabbro, were no doubt erupted at very different periods; the gabbro probably coming first, the basic lava flows next, and the granite partly before the ascent of the nickel eruptive and partly after it. None of these rocks occupy areas of more than a few square

miles, so that they are insignificant in amount as compared with the nickel-bearing sheet.

Other eruptives.—There is another mass of eruptive materials, the Onaping tuff, consisting of volcanic ash and lapilli, which may be considered as probably having its source in the original magma; though now spread out as a thick layer between the ordinary water-formed sediments overlying the nickel eruptive. As its area is at least 200 square miles and its thickness two-thirds of a mile, its volume must be about 130 cubic miles; and before it underwent erosion it must have been far more extensive than now. Much of its materials fell as angular fragments of glass, now transformed into chalcedony, serpentine, etc., but mingled with the pyroclastic matter there are a good many well-rounded pebbles and bowlders of quartzite and granite, suggesting ordinary water action. Probably the ash fell into the same body of water which deposited the other sediments of the basin.

An analysis of the tuff by Professor Walker gives the following results:

SiO_2	59.93
Al_2O_3	12.12
FeO	10.56
MgO	5.19
CaO	4.49
Na_2O	3.80
K_2O	.97
MnO	trace
Loss by ignition	1.57
Total	98.63

Its composition is somewhat different from the average of the nickel eruptive as given on a former page, but not so different that we cannot suppose it to have come from that source before the laccolithic sheet had reached its present position. The vitrophyre tuff must have been flung from some volcano of which we no longer have a trace, at a distinctly later time than the lava sheets of basic norite described before, since we have reason to believe that the whole series of sediments of which the tuff forms a part extended over the area occupied by the older norite before the sheet of nickel eruptive was injected between them.

In addition to the comparatively large masses of eruptive rock thus far mentioned, there are later dike-rocks penetrating them all impartially, including large dikes of very fresh olivine diabase, which cross norite, ore bodies, granite, and different kinds of Huronian rocks; and a few small dikes of still later granite which cut the olivine diabase, and are therefore the latest rock in the district except the widespread pleistocene beds of clay, sand, and gravel.

The dike-rocks are separated from the older eruptives by a very long interval of time, and may have no connection with the original nickel-bearing magma.

TIME RELATIONS AND CONCLUSIONS

The oldest rocks of the Sudbury district are mainly sedimentary, including small patches of green schist and banded silica of the Iron formation, belonging to the Keewatin; quartzite, graywacke, and slate of the Lower Huronian, associated with certain schists and greenstones; and Middle Huronian graywacke conglomerate in a small area north of Ramsay Lake.

The granite and gneiss mapped as Laurentian penetrate the sedimentary rocks of the Lower Huronian, and so are later in age; but their relation to the Middle Huronian is not known. The basic norite underlying the main nickel range may be later than the Laurentian, though this is not certain, since the two rocks have not been found in contact. It is later than the Lower Huronian, since it incloses blocks of graywacke and quartzite.

Upon the planed-down edges of these older rocks after a great lapse of time the Trout Lake conglomerate was deposited, followed by the eruption of ash and lapilli forming the thick sheet of the Onaping tuff. Next came the quiet deposit of mud forming the Onwatin slate, and of sand, forming the Chelmsford sandstone.

The age of this series of rocks is uncertain, but they have been looked on as probably the equivalents of the western Animikie, now classed as Upper Huronian. Accepting this classification, the sedimentary rocks range from the top of the Keewatin, the oldest known formation, to the Upper Huronian or Animikie. Next came the flood of nickel-bearing magma spreading as a sheet a mile and a quarter thick between the Trout Lake conglomerate and the lower

rocks; followed by the collapse of the older rocks because of the removal of the molten mass from beneath, the result of this being the synclinal arrangement of the nickel eruptive and the overlying sediments. Some coarse-grained granite or granitoid gneiss was erupted at about the same time or a little before. Not long after the sheet was spread out and solidified, fine-grained granite pushed up through it or beside it; perhaps the last product of the original magma.

The nickel-bearing sheet and the granites just mentioned were post-Huronian in age, perhaps Cambrian or even Ordovician. When all had cooled and hardened, including even the most fluid part of the magma, the ore in the hollows beneath the sheet, fissures cut across all the rocks and were filled with olivine diabase. Last of all a small supply of acid magma penetrated fissures crossing the diabase dikes. The date of this latest of the granites cannot be determined, since there are no fossiliferous rocks in the region.

From the outline just given it will be seen how long and complex a history there is behind the Sudbury nickel ranges and their associated rocks, including sedimentary rocks of four ages, a great sheet of volcanic ashes, norite or gabbro of three ages, granite of at least three ages, and dikes of diabase; the events beginning with the earliest known period of the earth's history and ending in lower Paleozoic times.

If the inferences suggested regarding the relationships of the eruptive rocks are correct, the same magmatic source has provided medium gabbro, very basic norite, rather acid volcanic ash, coarse-grained granite, somewhat acid norite merging upward into pegmatite and downward into nickel ore, and acid fine-grained granite. Whether the much later dikes of diabase and granite should be placed in the succession is doubtful.

The operations included the formation of coarse-grained plutonic rocks of a stocklike kind, flows of lava showing pillow and amygdaloidal structures, the flinging-out of vitrophyre tuffs mingled with some ordinary sediments, followed by the injection of the vast nickel-bearing sheet and its slow differentiation by gravity and the stoping and absorption of overlying rocks; so that the products of the original magma cooled in part very slowly at great depths, in part somewhat more rapidly as a sheet buried under 8,000 feet of sediments, in part

as surface lava flows, and in part as glass fragments due to explosive eruptions. The time required for all these manifestations of activity from the one eruptive hearth extended from the Lower Huronian to the Cambrian or a somewhat later period of the Paleozoic.

Just why the nickel eruptive magma with its great masses of ore and its varied segregation products should occur near Sudbury and nowhere else in the vast Archaean region of northern Canada, there are no means of deciding; but prospectors familiar with the ore and its accompanying rock have looked for them far and wide, but in vain. Pyrrhotite has been found in considerable amounts in other places, but not in association with norite and with only a minute percentage of nickel.

The Sudbury nickel-bearing sheet is unique as far as America is concerned, and far surpasses in magnitude and economic importance the small areas of nickeliferous norite of Scandinavia and other parts of Europe. Its great marginal ore deposits may be compared in size and origin with the segregations of titaniferous magnetite connected with large gabbro areas, and the percentage of iron which they contain would make them valuable ores of iron but for the presence of sulphur.

THE COMPOSITION OF THE RED CLAY

F. W. CLARKE

In the volume upon *Deep Sea Deposits*, issued as one of the reports of the "Challenger" expedition, there are published twenty-five analyses of the "red clays."[1] This sediment is now recognized as the most extensive and important of all oceanic deposits, for it covers 51,500,000 square miles of the sea floor and is characteristic of the greatest depths. It is, therefore, obviously desirable to know its average composition as exactly as possible, and for that reason the following investigation was undertaken.

Of the analyses above mentioned 21 were by Brazier, 2 by Hornung, 1 by Klement, and 1 by Renard. They are, however, not strictly comparable, as a glance at the recorded data will show, nor are they, from the point of view of the modern analyst, so complete as they should be. For example, that ubiquitous element, titanium, was not determined in any of the analyses, for at the time they were made, its importance and relative abundance were not appreciated. Other substances, which are common in clays, were neglected for similar reasons, but their significance is now better understood, and improvements in analytical methods have made it easier to search for them. In Brazier's analyses the alkalies were not estimated, but were reported by the other analysts; an omission in the first group that was not due to oversight, but to the limitations of the purposes for which the work was done. The general nature of the red clay was well established, its great variability in composition was clearly shown, and its relations to other clays were made sufficiently plain to satisfy all ordinary requirements.

Of late years, however, it has become a matter of interest to determine the relative abundance and distribution of the chemical elements; and in an inquiry of that sort so notable a substance as the red clay could not well be neglected. A new and more elaborate

[1] *Deep Sea Deposits*, pp. 198, 201, 425–35.

analysis of it, therefore, seemed to be required, and to that end two methods of investigation were available. First, it was possible to make a number of individual analyses of separate samples, from which an average might be computed. Secondly, one composite sample could be analyzed, giving the desired information once for all. The first method, evidently, would have involved much labor, too much, indeed, to be justifiable. The second method would solve the problem equally well, but with greater ease and vastly less expenditure of time. The second, therefore, was chosen. Through the kindness of Sir John Murray, and his secretary, Mr. James Chumley, fifty-one samples of the red clay, from as many localities, and approximately equal in weight, were combined into a single sample, and that was analyzed by my associates in the laboratory of the United States Geological Survey.[1] The results of the composite analysis will be given presently.

The composite sample, as made up by Mr. Chumley, contained 35 samples from the dredgings of the Challenger expedition, 12 collected by the "Egeria," 2 by the "Waterwitch," and 2 by the "Penguin." Of these, 8 samples were collected in the Atlantic, 2 in the Indian Ocean, and 41 in the Pacific. The "Challenger" localities were stations Nos. 5, 9, 26, 27, 29, 160, 165, 181, 215, 221, 226, 228, 229, 230, 238, 240, 241, 244, 247, 251, 253, 254, 255, 256, 258, 259, 275, 277, 285, 286, 288, 294, 329, 330, and 353. These stations can be identified by reference to the published reports of the expedition.[2] The geographic range of the collection is evidently large enough to give a significant average, and the number of individual samples was also adequate. Twelve of the localities enumerated above are represented among the analyses already published in the volume on *Deep Sea Deposits* and are there indicated by their station numbers. The other localities furnished material hitherto unstudied chemically.

The new analysis of the clay was made upon the air-dried and unwashed sample. It, therefore, included adherent sea salts, and hygroscopic moisture, varying in these respects from the earlier

[1] The analytical methods employed were those prescribed by Hillebrand, in *U. S. G. S. Bulletin, No. 305.*

[2] A chart showing the position at which each sample was taken, was also furnished with the material sent for analysis.

analyses. The magnitude of these variations, however, was determined, and appears in the figures given below. The final data are as follows:

A. General analysis, by Mr. George Steiger.
B. Portion soluble in cold water, by Mr. George Steiger.
C. Special determinations, by Dr. W. F. Hillebrand.
D. Special determinations, on material concentrated from 150 grammes of clay, by Dr. E. C. Sullivan.

These last determinations were checked by blank experiments upon equal quantities of the reagents employed in the research.

TABLE I

	A.	B.	C.	D.
SiO_2	45.32	none	BaO.....0.16	CuO.....0.02
Al_2O_3	13.26	none	Cr_2O_3....0.011	PbO.....0.007
Fe_2O_3	7.20	none	V_2O_3.....0.035	ZnO.....0.004
FeO	0.70	none	MoO_3....trace	As_2O_3....0.0007
MgO	3.05	0.21		
CaO	6.82	0.19		
Na_2O	3.63	2.01		
K_2O	2.43			
H_2O at 106°	3.28	....		
H_2O above 106°	5.93	....		
TiO_2	0.82	....		
CO_2	3.91	....		
P_2O_5	0.25	....		
SO_3	0.48	0.39		
Cl	2.77	2.73		
F	none	....		
Cr_2O_3	0.01	....		
NiO, CoO	0.032	....		
MnO_2	1.01	....		
BaO	0.17	....		
SrO	0.046	....		
Li_2O	none	....		
V_2O_3	0.023	....		
	101.141	5.53		
Less O=Cl	0.62	0.62		
	100.521	4.91		

Zirconia and the rare earths were sought for by Dr. Hillebrand, but not found. Titanium, chromium, vanadium, barium, strontium, nickel, copper, lead, zinc, arsenic, and molybdenum were not reported in the "Challenger" analyses. Their widespread distribution in the igneous rocks is, however, well recognized. The absence of

lithium and fluorine is noteworthy. The unusually high proportion of manganese suggests the presence of disseminated or incipient manganese nodules, like that so admirably analyzed by Gibson.[1] In his work several of the rarer elements were determined; so that their existence in the oceanic sediments is no new discovery. The fact of their general distribution, however, remained to be proved.

In order to establish the true composition of the clay substance, some deductions must be made from the analysis as it is now stated. Hygroscopic water and soluble matter must be eliminated, and also the calcium carbonate which is represented by the CO_2. The composition of the aqueous extract, as given by Mr. Steiger's figures, is very near that of the sea salts. I have therefore taken Dittmar's analysis of sea salts as a standard, and subtracted their equivalent, as measured by the chlorine in the unleached clay, from the analysis of the latter. A slight excess of SO_3 remained, which I have also thrown out as representing gypsum. In short, from the general analysis I have withdrawn the water lost below 106°, the sea salts, the calcium carbonate, and a little gypsum, and recalculated the remainder to 100 per cent.

For comparison, I have combined the twenty-five analyses of the "Challenger" report into an average, from which similar subtractions, so far as they were needed, have been made. In this case only gypsum and calcium carbonate were rejectable. As for the combination, its value is not very great, because of the inequality shown by the individual analyses. Only in four of the latter were alkalies determined, and the mean of those four I have assumed to be representative of all. The ferrous oxide is even more doubtful, for it was only determined in one of Hornung's analyses, and neglected in the others. Still, as will be seen in the subjoined table, the comparison is not without significance, and even if it is not perfect, it is better than none at all.

The minor elements, not shown in the "Challenger" analyses, only sum up, altogether, to 1.36 per cent. Apart from these the comparison is satisfactory in some respects, not so in others. In silica, alumina, and water, the agreement is fairly good, but in iron,

[1] *Deep Sea Deposits*, pp. 422, 423.

the old analyses range much higher than the new. Possibly for the individual analyses, the reddest and therefore the most ferruginous samples were chosen for examination, as being presumably the most typical.

TABLE II

REDUCED ANALYSES

	Composite Analysis	Challenger Average
SiO_2	54.48	54.28
TiO_2	0.98	.....
Al_2O_3	15.94	16.41
Cr_2O_3	0.012	.....
Fe_2O_3	8.66	13.58
FeO	0.84	1.26
NiO, CoO	0.039	.....
MnO_2	1.21	1.62
MgO	3.31	1.76
CaO	1.96	0.74
SrO	0.056	.....
BaO	0.20	.....
K_2O	2.85	1.61
Na_2O	2.05	1.37
V_2O_3	0.035	.....
As_2O_3	0.001	.....
MoO_3	trace	.....
P_2O_5	0.30	0.35
CuO	0.024	.....
PbO	0.008	.....
ZnO	0.005	.....
H_2O	7.04	7.02
	100.000	100.00

On the proximate or mineralogical composition of the red clay, I have no important suggestions to offer. That problem was discussed at some length, in the "Challenger" report, on the basis of Brazier's analyses. In those analyses there was discrimination between the portion of the clay soluble in strong hydrochloric acid and the portion insoluble. In nearly every case the soluble ferric oxide was reported in excess of the insoluble; from which I am inclined to suspect that the iron of the clay is present, at least partially, in limonitic or glauconitic combination. The new, composite analysis shows a quantity of potash which suggests the presence of glauconite. The latter compound may well exist in a diffused

form, quite unlike its common granular variety, and therefore not so readily recognized. This is a mere suspicion, not entitled to much weight at present, but worth considering in future investigations. My specific problem has been to study the distribution of the chemical elements in nature, and to that end the composite analysis of the red clay is a step forward.

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ADDENDUM

Since the foregoing pages were written I have received from Sir John Murray a composite of 52 "terrigenous" clays, dredged up from oceanic depths ranging from 140 to 2,120 fathoms. In the nomenclature of the "Challenger" expedition, 48 of the individual samples are classified as "blue muds," and 4 as "green muds." Twenty-three of the clays were collected by the "Challenger;" the others were brought in from voyages of the "Buccaneer," "Dart," "Egeria," and "Rambler." The range of collection, as in the case of the "red clay," was world-wide, and all of the great oceans are represented in the composite sample.

Molybdenum and zirconium were not detected. Nickel, cobalt, lead, zinc, and arsenic, which were reported in the red clay, were not looked for. Apart from these trivial omissions, the red and terrigenous clays are fairly comparable. The red clay is lower in silica and alumina, but higher in iron than the muds, and other minor differences appear. The high manganese of the red clay may be correlated with the abundance of manganese nodules in the greater oceanic depths. The results of analysis appear in the following table:

A. General analysis by Mr. Steiger.
B. Portion soluble in water.
C. Analysis reduced to standard form by rejecting soluble salts, calcium carbonate, and hygroscopic water, and recalculation of the remainder to 100 per cent.

TABLE III

	A.	B.	C.
SiO_2	46.64		57.09
TiO_2	1.04		1.27
Al_2O_3	14.08	.14	17.24
Cr_2O_3	.044		.05
Fe_2O_3	4.14		5.07
FeO	1.88		2.30
MnO	.10		.12
MgO	1.95	.18	2.17
CaO	7.20	.38	2.04
SrO	0.25		.03
BaO	.05		.06
K_2O	1.84		2.25
Na_2O	2.98	2.12	1.05
V_2O_3	.028		.03
P_2O_5	.17		.21
CO_2	4.05		....
SO_3	.32	.32	....
S	.11		.13
Cl	2.25	2.25	....
CuO	.016		.02
C	1.38		1.69
H_2O at 105°	4.73		....
H_2O above 105°	5.86		7.18
	100.883		100.00
Less O = Cl	.56		
	100.323		

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THE GLACIATION OF THE UINTA MOUNTAINS[1]

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OUTLINE

Location and General Physical Features of the Range.
The Extent of Glaciation.
Comparison of the Glaciation of the North and South Slopes.
Glacial Epochs.
The Influence of Topography upon the Ice.
The Influence of Ice upon the Topography.
Polished and Striated Surfaces.
Influence of Glaciation on Drainage.
Post-glacial Work.
Glaciation and Irrigation.

LOCATION AND GENERAL PHYSICAL FEATURES OF THE RANGE

The Uinta mountains are located in the northeastern portion of Utah. They consist of a single range of peaks extending in a general east-west direction. If the axis of the range were continued westward it would cross the Wasatch range nearly at right angles and enter the Bonneville basin a few miles south of Salt Lake City. Most of the range is included in the Coalville, Hayden Peak, Gilbert Peak, and Marsh Peak quadrangles of the Topographic Atlas published by the U. S. Geological Survey.

These mountains rise somewhat gradually above the plateau countries to the north and south. They reach their maximum elevation in the central portion of the range where the highest peaks are from 13,400 to 13,525 feet above the sea. The maximum elevation of the mountains above the surrounding country is about 7,000 feet. From the high central portion of the range the crest-line descends gently both to the east and to the west.

The width of the range is greatest in the central portion, where it measures, in a north-south line, fully 35 miles. To the east and west of the central portion the decrease in width is very notable. To the

[1] Published by permission of the director of the U. S. Geological Survey.

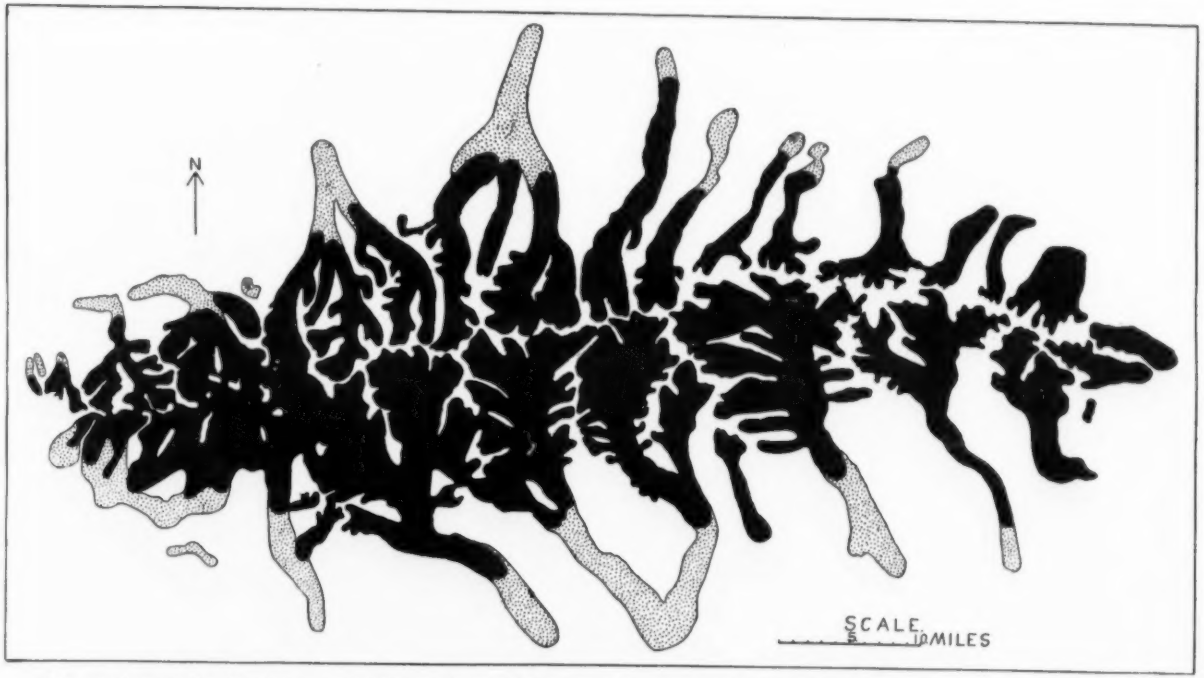


FIG. 1.—A map showing the extent and distribution of Pleistocene glaciers among the Uinta Mountains. Black represents areas covered by later epoch glaciers. Dotted portions represent additional areas covered by earlier epoch glaciers.

west the narrowing is symmetrical, and the terminus of the range is lobate in form, being sharply defined at the north and south by the valleys of the Weber and Provo rivers respectively. To the east the narrowing is not so pronounced or symmetrical, and, associated with the general flattening-out of the range in that direction, helps to account for the less conspicuous terminus at the east.

All the great canyons of the Uintas head near the crest of the range and descend approximately north or south. Since the axis of the range is nearer the north than the south margin, the north slope canyons are shorter than those on the south slope. All of the larger canyons have the characteristic U-shaped form due to glaciation. They have been well cleaned out by the ice in their upper portions, but in the middle and lower portions they contain heavy morainic deposits.

On the north slope, at the heads of the canyons, the basins vary from one to twelve square miles in area, while on the south slope they commonly include from twenty to thirty square miles (see Fig. 1). This difference, which had a very notable influence on the size of the glaciers, is consistent with the general structure of the range and will be discussed later.

THE EXTENT OF GLACIATION

At the period of maximum extension the ice covered by far the greater portion of the mountains west of Longitude 109 degrees, 40 minutes, and in a few cases extended beyond the mountains into the lower country to the north and south. The maximum extension of glaciation in an east-west direction was 82 miles, and in a north-south direction 42 miles. The total area covered by ice was something over 1,000 square miles. The portions of the range that rose above the ice near the crest-line were lofty peaks and narrow, rugged divides (see Figs. 2 and 3). Near the western end of the range in the region about Hayden Peak, Bald Mountain, Reids Peak, and Mount Watson, there was a great ice cap (see Fig. 1). Above this ice cap a few lofty summits (Fig. 2) rose as nunataks and helped to direct the movement of the ice into the canyons leading from this great center of accumulation. Six of the larger glaciers in the western portion of the range originated in this ice cap.

On the flanks of the range the areas not covered by ice were between the great canyons. These areas became broader and broader to the north and south, beginning as narrow ridges near the crest-line (Fig. 3), and broadening to plateau-like areas near the foothills. The portion of the range that rose above the snow-fields associated with the glacier must have been much less than that which rose above the ice. There is no way of determining how high the snow rested, but it is fair to assume that aside from a few lofty peaks

FIG. 2.—A portion of the Provo Basin. The passes have been glaciated but the peaks rose above the ice. The lake in the foreground is in a rock basin that was gouged out by the ice.

and narrow ridges the range appeared as a long white arch, rising about 7,000 feet above the country to the north and south, and suggestive, in form at least, of a partial reconstruction of the great Uinta anticline.

Most of the catchment areas in which glaciers were formed are 10,000 feet or more above the sea. A few favorably located basins between 9,000 and 10,000 feet furnished ice. The lower glacier basins are all near the western end of the range, where the snowfall was presumably greatest. Near the eastern margin of glaciation there are many basins above 9,000 feet in elevation that did not

contain ice. Three of the basins below 10,000 feet contained ice during the earlier epoch, but not during the later, indicating that, in general, a greater elevation was necessary for the formation of glaciers during the later than during the earlier epoch.

The glaciers extended southward and northward from the main crest-line, reaching their greatest lengths in the central portion of the area and decreasing in length both to the east and west, thus exhibiting a dimensional symmetry appropriate to the form of the range (see Fig. 1). The longest glacier was 27.5 miles in length; the shortest independent glacier was 1.5 miles long. During the earlier epoch there were thirty distinct glaciers. Most of these thirty glaciers may more properly be referred to as great systems, for in most cases they were formed by the union of from two to eight glaciers. During the later epoch, when the ice was not so extensive, fewer glaciers united, especially on the north slope, and therefore there was a larger number of distinct termini to the ice. The total number of independent glaciers during the later epoch was thirty-nine.

If the great systems of the earlier glaciers be subdivided and the tributary glaciers be counted as independent glaciers, there were:

8	glaciers	20 miles or over in length
3	"	15 to 20 miles in length
9	"	10 to 15 " " "
21	"	5 to 10 " " "
63	"	1 to 5 " " "

or a total of 104 glaciers over 1 mile in length.

COMPARISON OF THE GLACIATION OF THE NORTH AND SOUTH SLOPES

The lengths of the glaciers on the north and south slopes were, on the average, during the earlier epoch, about ten and sixteen miles, respectively. During the later epoch the lengths of the glaciers on the north and south slopes were about eight and ten miles, respectively. There were but two glaciers on the north slope that reached twenty miles in length, while on the south slope there were six that exceeded that length. The lower limits of glaciation on the two slopes are shown in the following table:

	Maximum Lower Limit during Earlier Epoch	Maximum Lower Limit during Later Epoch	Average Lower Limit during Earlier Epoch	Average Lower Limit during Later Epoch
North Slope	7,200	7,500	8,165	8,500
South Slope	6,600	7,250	7,661	8,112

The explanation of these striking differences seems to rest fundamentally on the general structural conditions in the range. The fact that the crest-line is nearer the north than the south margin of the mountains is of extreme importance. As a consequence, the north slope canyons are shorter than those on the south slope. They descend more quickly to elevations where ablation overcame the onward movement of the ice. Furthermore, the basins on the north slope are in a zone of inclined strata, while the south slope basins are located in the midst of essentially horizontal beds. These structural conditions account for the greater development of the catchment areas on the south slope than on the north slope. The widening of the basins, to be discussed more fully later, progressed more rapidly in the region of horizontal strata than where the beds are inclined. The larger catchment areas and the longer canyons are sufficient to explain the more extensive glaciation on the south slope. These factors seem to have outweighed in importance the greater protection from the rays of the sun on the north slope and the more favorable location for the lodgment of wind-blown snows on the north. The angle of the sun's rays must have caused more rapid melting on the south side, and the prevailing southwest wind must have carried much snow from the southern catchment areas and contributed to the northern fields, and yet, with the immense basins and long routes to low altitudes, the south slope glaciers far exceeded in magnitude those on the north slope.

GLACIAL EPOCHS

The chief facts about the extent of the ice during the different glacial epochs have been given. On the average, the earlier glaciers advanced from five to six miles farther down the canyons than did the later. In three basins there appears to have been ice during the earlier epoch and not during the later. A comparison of the lower

limits of glaciation during the two epochs is shown in the table already given.

The recognition of distinct glacial epochs among the mountains has associated with it some peculiar difficulties. When ice descended

FIG. 3.—One of the sharp divides in the basin region.

a canyon it was quite apt to obliterate all traces of any earlier ice advances through the same course. This was particularly true if the later ice advanced as far as any earlier ice. The chances of finding buried drift in these restricted courses of the ice are therefore much poorer than in the open country invaded by the continental

ice sheet. The mere fact that the area in which the data must be found, to prove distinct epochs for a given canyon, is so small, enhances the difficulties in the problem, and greatly reduces the chance of a demonstration. Where the later ice did not advance as far as the earlier, the case is more hopeful. In fact, in every case where distinct epochs have been determined in the western mountains, so far as the writer is aware, the earlier ice was more extensive than the later. In such cases the outer moraines have been subject to the processes of weathering and erosion for a longer period than the later or inner moraines. There may also be, associated with the two distinct systems of moraines, distinct outwash-deposits. These outwash-deposits must have a genetic relationship with the terminal moraines of the two epochs, and the older alluvium or valley-train may be expected to have suffered greater erosion than the younger. The composition of the glacial drift in a mountain canyon will be essentially the same each time that ice descends to a given point. But if the drift contains some easily weathered material, such as the coarsely crystalline rocks, the difference in the amount of weathering or disintegratio nof the bowlders may become a strong argument. Among the Wasatch Mountains the older and the younger moraines may be easily distinguished by the difference in the amount of weathering. Among the Uintas this line of evidence is almost entirely wanting. The drift among the Uintas is composed largely of quartzite, in fact so largely that in most cases it is difficult to find a specimen of any other kind of rock in the drift. The drift of certain canyons is composed entirely of quartzite. Furthermore, the quartzite of the Uintas is so hard that the bowlders in preglacial conglomerates, derived largely from this formation, appear nearly as fresh as those in the youngest glacial deposits. The only difference that can be made out in the amount of weathering of the preglacial quartzite conglomerate and the quartzite moraines is that in the former there are more and larger bowlders that have been fractured, presumably by changes in temperature and by frost.

The determination of two epochs of glaciation among the Uintas rests chiefly upon these points:

1) There are two distinct systems of moraines in each of the main canyons.

2) The outer moraines are much more deeply eroded than the inner. Usually the outer terminal moraine has been entirely removed by erosion.

3) In some cases, where an older lateral moraine rests on a canyon slope above a younger moraine, the difference in the amount of erosion which each has suffered is very marked. Often there are valleys crossing the upper moraine which fail to cross the lower, and therefore appear as blocked valleys in drift above the lower moraines,

FIG. 4.—A glacial cirque in the western portion of the Uinta Mountains. The vertical walls and comparatively even floor are common characteristics of the catchment areas in the range.

just as blocked valleys in rock appear in the rock above the upper moraines.

4) Corresponding to the greater erosion in the outer moraines, there has been greater deposition. In many of the canyons, immense alluvial fans have been developed by side-streams that enter the main valleys at points below the terminal moraines of the later epoch and above the terminal moraine of the earlier epoch.

5) Depressions in the older drift have commonly been filled with alluvium. In this way, possible lakes or marshes have been obliterated. In the older moraines there are but few lakes and marshes while in the younger moraines lakes and marshes are common.

6) In three canyons there appears to have been ice only at a much earlier period than that of the later epoch.

7) In some cases two distinct valley trains have been determined, one being associated with the outer and the other with the inner moraines.

The alternative interpretation of the glacial deposits in the range is that the so-called younger moraines are recessional moraines deposited by the same ice that built up the outer older ridges. The marked differences in the age of these two series of moraines make this interpretation unsatisfactory. The time necessary for the removal of the outer terminal moraine, and the excavation of broad valleys in which the younger valley trains were deposited, must have been many times, perhaps ten, or twenty times, as long as the period that has elapsed since the final melting of the ice.

THE INFLUENCE OF TOPOGRAPHY UPON THE ICE

In an earlier paragraph it has been pointed out that the formation of the Uinta glaciers has been controlled by the size and elevation of the catchment areas. The case is equally clear that the movements of the ice were, in a large measure, dependent upon the topography of the range. At some places the divides were covered by ice, and yet in such places the underlying rock divides controlled the direction of ice movement, causing movement in opposite directions in a continuous ice mass. In the catchment areas the movement was in general pointed toward the canyon. From certain catchment areas the ice was forced to pass around isolated peaks and ridges that rose above the ice as nunataks; in some cases, to divide and move down different canyons on the same slope. The canyon ice was frequently forced by some projecting rock spur to swing to one side or the other. At constricted portions in the canyons the ice responded somewhat as rivers do and worked its way through the narrows, to deploy as soon as the walls of the canyon permitted. At several points the canyon ice was required to turn at right angles in order that it might move down valley.

THE INFLUENCE OF ICE ON THE TOPOGRAPHY

While the ice responded to topography, and in a large measure was controlled by the physical features of the range, yet at the same

time it was modifying the forms encountered, changing the shape of the great canyons, and building new forms.

Before the first Pleistocene snows fell on the Uinta Mountains, the heads of the great canyons may be fairly assumed to have been narrow V-shaped notches, reaching in most cases nearly to the crest-line of the range. The first ice was formed in these narrow canyon heads, and the earliest movement must have been distinctly down canyon. As the ice at the heads of the canyons increased in thickness, there came to be a notable movement down the sides of the gorge, concentrating the ice in the canyon and causing further movement down stream. With the movement of the ice on the side slopes, these miniature catchment basins were both widened and lengthened. About the margin of the ice fields weathering and ice plucking was in progress. Such work has been pointed out by Johnson[1] to be going on today at the base of the Bergschrund. In this way the catchment areas were increased in size and changed into cirque-like forms (see Fig. 4). Such work has been described by Penck[2] as follows:

> Glaciers not only exercise a sapping action along their sides, but also at their very heads, if they are here overlooked by rock cliffs. There is always a marginal crevasse, called in German, Randspalte or Bergschrund, which separates the moving ice from the rocks which overlook it. The material loosened here by weathering falls down from the rock walls into this crevasse and arrives at the bottom of the névé, where it is pushed forward by the mass grinding the bottom of the glacier. By this, not only the formation of screes around the glacier is hindered, but also the surrounding cliffs are constantly attacked, for the erosive action begins just at their foot and saps them. Glaciers therefore, which are formed on slopes in broadly open valley basins, surround themselves finally by cliffs, which are pushed backward much as are the cliffs around the gathering basin of a torrent.

Just south of the main crest-line, weathering and the plucking work of the ice went on under the most favorable conditions. There the strata are essentially horizontal and sufficiently variable in hardness to favor rapid disintegration. The giving-way of the softer beds left the overhanging harder strata exposed. Cliff and talus slopes developed, and the ice, working sideward and headward, or in general

[1] *Journal of Geology*, Vol. XII, p. 573.

[2] *Journal of Geology*, Vol. XIII (1905), p. 15.

outward, around the margin of the ice field, would work these steps or benches farther and farther back. Sometimes a very resistant layer of quartzite served for several square miles as a base to which the quarrying work of the ice went on. Then another resistant layer, 10, 20, or even 200 to 300 feet higher, would serve as the floor of the quarry. The work therefore went on in something of the fashion in which men widen and deepen quarries in similar formations. Many abandoned benches remain today about the margins of the great catchment areas.

Corresponding to the widening of the basins, there was a narrowing of the divides between the heads of the canyons and of the main crest of the range. Some of the divides (see Fig. 3) were so reduced that it is dangerous to try to walk along them. Others were surmounted and greatly reduced by the ice. The main crest-line was sharpened, and the peaks were given greater prominence.

In the canyons the great change was the development of the broad U-shaped troughs. The preglacial forms were largely obliterated. The canyons were widened and deepened. In this process many tributaries were left as hanging valleys with their lower ends several hundred feet above the main stream. Preglacial erosion lines, and asperities common to the slopes of unglaciated canyons, were commonly rubbed off as far up as the ice rested.

In the bottom of the gorges, on the canyon walls, and in the basins, the glaciers built up new topographic forms. The terminal moraines have an average depth of about 400 feet. In one instance, however, it is clear that there is at least 1,000 feet of morainic material at the mouth of the canyon. These moraines are often ridgelike in form but where the glaciers pushed out on the lowlands bordering the mountain range, they have a hummocky topography similar to the terminal moraines left by the continental ice sheet of the interior region. At intervals, up stream from the terminal moraine it is customary to find other morainic ridges or belts crossing the valley in the manner of recessional moraines. Above these recessional moraines lakes are sometimes located, but more commonly swamps, which are being drained as the main streams lower their courses through the morainic dams. The lateral moraines are lodged as ridgelike forms on the valley slopes. The crest-lines of these lateral ridges increase in

elevation above the stream bed for several miles up the canyon from the terminal moraines, until, near the basin region, the canyon walls become too steep to permit the lodgment of loose débris. The elevation of the lateral moraines indicates that the ice in many of the canyons was but 600 or 700 feet thick, but where the larger glaciers existed the ice was from 1,500 to 2,000 feet thick, and in one case 2,500 feet thick. The extensive terraces extending down stream from the terminal moraines are remnants of valley trains deposited by the waters associated with the glaciers.

POLISHED AND STRIATED SURFACES

The polished and striated surfaces of bed rock are restricted almost exclusively to the basin regions. In the areas where the drift is scarce, striae, grooves, polishings, and *roches moutonnées* are common. Square miles of bed rock are exposed in the higher portions of the range, where the signs of ice action are beautifully shown. In many of the passes in the main crest-line, glaciated surfaces appear. Striae have been found as high on some of the peaks as any other signs of ice action, and about the marginal portions of the basin regions ice action is often recorded both in glaciated surfaces and ice-gouged basins in the hard quartzite rock. A few striated rock surfaces have been found deep in the canyons and on benches or shoulders on canyon walls.

INFLUENCE OF GLACIATION ON DRAINAGE

The hundreds of glacial lakes and marshes indicate, especially in the basin region of the range, how generally the drainage has been modified by the ice. Scarcely a basin exists where waters are not yet ponded by the morainic deposits or retained in rock basins gouged out by the ice. In a few cases tributary streams in unglaciated valleys have been ponded by lateral moraines of a main canyon. Terminal and recessional moraines have in some canyons blocked the courses of the main streams and caused the formation of chains of lakes. At the close of the glacial period such chains were much more common than they are today, but in their places are chains of meadows, separated from each other, as the former lakes were, by morainic ridges. There are now more than 550 glacial lakes among

the mountains. In the catchment basin of Provo Canyon there are at least forty-three lakes, and from the summit of Bald Mountain overlooking the area formerly covered by the ice cap seventy lakes may be seen. In a few cases streams are today partially ponded by morainic dams. In these cases the drift is not sufficiently compact to hold the waters until they rise and overflow, but, seeping through the loose deposits, the waters issue a short distance down the canyon as large springs. The glacial lakes vary in their longer diameters from a few rods to one mile and a half. Most of them, however, are less than half a square mile in extent.

The hanging valleys may also be mentioned in this connection, for they are instances of marked changes in drainage. In this way scores of tributary streams have been thrown out of adjustment with their mains. Falls and rapids have been caused which centuries of work may not remove from the stream courses.

POSTGLACIAL WORK

Since the ice last left the Uinta Mountains, the work of weathering and erosion has been, with the exception of certain inner gorges on the south slope, trivial and insignificant. The moraine material of the later epoch is but little disintegrated, and most of the streams are yet engaged in cleaning away the glacial débris from their courses. Near the summits changes in temperature, frost, gravity, and moving névé, have so combined as to produce extensive talus accumulations about the margins of the basins. The inner rock gorges in the main south slope canyons are the most striking postglacial features in the range. On the average they are fifty to eighty feet deep and from five to six miles long. They are limited to the upper portions of the canyons, and do not appear to be due to a general rejuvenation of the streams. They are in those portions of the canyons where the deepening by the ice was greatest, and therefore where the stream bed would be expected to be relatively low, and yet these inner rock gorges are distinctly below the level of ice wear and are not glaciated. The favorite hypothesis for the explanation of these gorges has been a slight postglacial uplift along an east-west line about ten miles south of the axis of the range.

GLACIATION AND IRRIGATION

The present streams from the Uinta Mountains, if under control, would furnish enough water to irrigate hundreds of square miles in the lower country. If the glacial lakes were connected directly with the streams and used as reservoirs, the irrigating capacity of the streams would be immensely increased. Usually a relatively inexpensive dam would control the waters of these natural reservoirs. In most cases the lake waters could be easily increased a few feet in depth, and often spread over many additional acres of land. In a few cases simple efforts have been made to control the waters in such lakes. China Lake, in the east fork of Smith's Fork, now serves as a reservoir. At the south end of Lake Washington in the Provo Basin a dam was built which, if effective, would have raised the waters in the lake a few feet and reserved a large supply of water for the latter part of the growing season. The dam is now broken, and the outlet of the lake is being gradually lowered by the outflowing waters. In many cases outlets of former glacial lakes could be closed and new reservoirs made. Often the younger terminal moraines in the canyons have but narrow notches cut through them. If these post-glacial notches were closed, there would be extensive reservoirs in the lower portions of the canyons.

Most of the irrigable land south of the mountains is at present owned by the Ute Indians. The Indians carry on some agricultural work, but only near the streams, where the land is very easily watered. The country north of the range is inhabited by ranchmen, who find it more and more necessary each year to raise fodder for their stock. The land is being rapidly taken up and fenced off for private ranges. In this country irrigation is practiced somewhat extensively, and yet little or nothing has been done to control the waters in the basin region or to develop new reservoirs lower down in the canyons. Each year the streams are lowering the outlets of the lakes and both widening and deepening the cuts through the moraines in the canyons, and therefore the amount of work necessary to get control of the water supply in the range steadily increases.

NOTES ON THE PENNSYLVANIAN FORMATIONS IN THE RIO GRANDE VALLEY, NEW MEXICO[1]

C. H. GORDON
Knoxville, Tenn.

Introduction.
General Relations of the Pennsylvanian Rocks in the Rio Grande Valley.
The Magdalena Group.
    General Description.
    The Sandia Beds.
    The Madera Limestone.
The Manzano Group.
Nomenclature.

INTRODUCTION

A number of papers have appeared in recent years concerning the Carboniferous formations in the Rio Grande Valley. As the observations therein recorded were almost wholly of a reconnaissance nature, it is not to be wondered at that more or less divergence is manifest in the views of the different writers concerning the stratigraphy of the region. This paper is based on observations made during a year's residence at Socorro, together with several months' field-work in connection with the investigation of the mines and mining districts of New Mexico under the direction of Mr. Waldemar Lindgren of the U. S. Geological Survey. The results of that investigation are to appear in a forthcoming bulletin of the Survey. In the present paper it is the chief purpose of the author to present a brief description of the rocks in the Rio Grande Valley which represent the lower part of the "Coal Measures" of adjoining regions, and to discuss their stratigraphical relations and the nomenclature connected with them. For these beds in the Survey paper above mentioned the name Magdalena has been adopted as a group term.

[1] Published by permission of the Director, U. S. Geological Survey.

GENERAL RELATIONS OF THE PENNSYLVANIAN ROCKS IN THE REGION

In the Rio Grande Valley the Upper Carboniferous or Pennsylvanian series is represented by a succession of limestone, shale, and

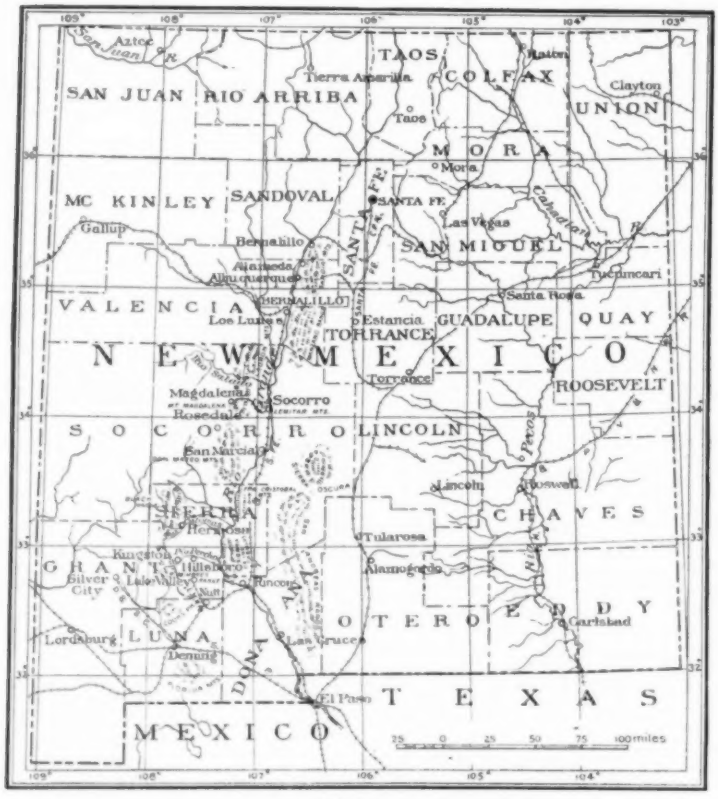
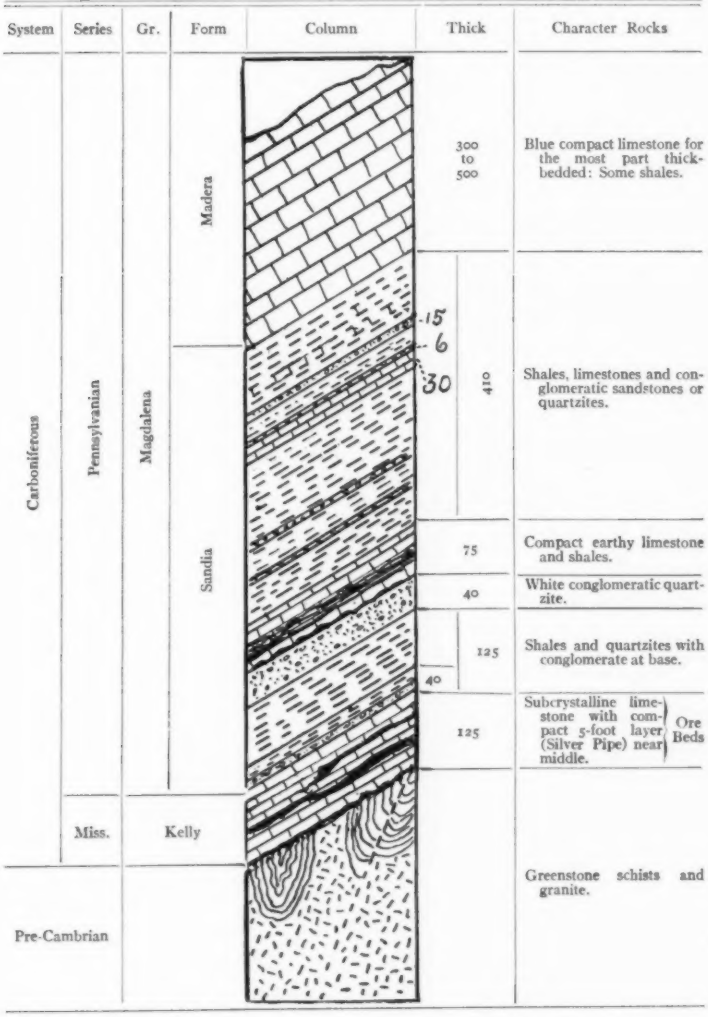


FIG. 1

sandstone formations, having an aggregate thickness of from 3,000 to 5,000 feet. These may be separated into two main divisions or groups, to the lower of which the name Magdalena is here applied, from the Magdalena Mountains, where they are well exposed, while the upper division comprises the formations, chiefly sandstone, to

MAGDALENA SECTION



which Herrick[1] applied the term Manzano, from the Mountains of that name northeast of Socorro, in Valencia County, together with the limestones found overlying the sandstones in regions south of Bernalillo County, which Lee[2] has shown to belong to the series.

Southward in Sierra County, where the Pennsylvanian and Lake Valley (Lower Carboniferous) formations occur together, the relations are those of apparent conformity. The Lower Carboniferous formations thin out northward in Socorro County and are not known to occur north of the Ladrone Mountains. In the Magdalena Mountains the basal beds of the Pennsylvanian are conglomerates and shales, which rest with apparent conformity upon the Kelly (Lower Carboniferous) limestone. Northward in Bernalillo County the Pennsylvanian rests unconformably upon granites and other rocks of supposed pre-Cambrian age. A well-marked unconformity occurs also at the base of the Manzano division east of Socorro, as shown by Herrick,[3] who first recognized it and who states that this is evidently an unconformity by overlap. Lee[4] has shown that the Manzano beds are separated from overlying formations by great erosional unconformity. The twofold division of the Pennsylvanian formations is sustained therefore both by faunal distinctions, according to Dr. George H. Girty,[5] and by relations of unconformity as well. The faunal studies thus far made do not show any marked change in the life represented within each division, and the subdivisions are based entirely on lithological distinctions.

THE MAGDALENA GROUP

In general the Magdalena group may be said to be characterized by the predominance of limestone, while, on the other hand, sandstones constitute the most prominent feature of the Manzano group. In Sierra County the Magdalena group consists for the most part of massively bedded blue and gray limestone, interstratified with which

[1] C. L. Herrick, *Journal of Geology*, Vol. VIII, p. 115, 1900; *Am. Geol.*, Vol. XXV, p. 337, 1900; *Bull. Univ. New Mex.*, Vol. II, Fascicle No. 3, p. 4, 1900; *Jour. Geol.*, Vol. XII, p. 244, 1904.

[2] W. T. Lee, *ibid.*, Vol. XV, pp. 53, 54, 1907.

[3] *Jour. Geol.*, Vol. XII, p. 244.

[4] *Ibid.*, Vol. XV, p. 54.

[5] *Ibid.*, p. 54.

are thin-bedded limestone and dark-blue shale. Occasionally, a thin bed of sandstone may be seen. At Kingston, on the east slope of the Black Range, the basal beds consist of about 300 feet of dark-blue and gray limestone in thick beds with thin shale partings. The upper portion has about the same thickness and consists chiefly of blue and drab shale interstratified with several limestone formations varying from fifteen to twenty feet in thickness. Resting unconformably upon the shale formation are the red sandstones and shales of the Manzano group.

At Palomas Camp, in the Black Range, twenty-five miles north and a little west of Hillsboro, the county seat of Sierra County, and two miles east of Hermosa, the Rio Palomas has cut a gorge 1,000 feet deep through the sedimentary formations. The walls of the canyon are nearly vertical and consist almost wholly of blue and gray limestone of the Magdalena group. The lower half of the escarpment consists of limestone and shale in about equal development, while the upper portion is made up of hard, massively bedded gray limestone. About half-way up the cliff a few thin beds of quartzite appear interstratified with limestone. The overlying Red Beds of the Manzano group, together with some of the upper beds of limestone, have been removed by erosion at this point, but the red sandstones occur in considerable development a short distance to the northwest.

In the Caballos Mountains, about twenty-five miles east of Hillsboro, the group is represented chiefly by limestones, with some shale beds in the basal part, as at Hermosa, but we are unable to give details of the formation at this locality. They were observed resting with apparent conformity upon other limestones considered to be of Lower Carboniferous age, while below these, and separated from them by a thin bed of the Percha shale (Devonian), is a heavy development of limestone (900 ft.) belonging to the Mimbres formation (Ordovician).

The data at hand concerning these formations in Sierra County are insufficient to warrant an attempt to subdivide the group. The character of the beds at Hermosa suggests the twofold division observed farther north, and in connection with the character of the formations in adjoining districts indicates a gradual transition in sedimentation from shallow-water conditions at the north to deeper waters toward the south. With the progress of time the entire region apparently

assumed conditions of deep and clear waters wherein were deposited the extensive limestone beds which constitute the upper part of the division (the Madera limestone).

Northward in Socorro, Valencia, and Bernalillo Counties the Magdalena division comprises from 1,000 to 1,300 feet of sediments, the character of which in their typical locality will be seen from the section on p. 807.

The rocks of this division contain a characteristic Pennsylvanian fauna, which shows no essential variation from the base to the top of the series, but on lithological grounds they are readily separable into two formations, to the lower of which Herrick[1] gave the name Sandia Beds (or series), from the Sandia Mountains, where they were first studied, while the upper is known as the Madera limestone.[2]

Sandia beds.—In Socorro County the Sandia formation consists of alternating beds of blue and black clay shale, compact earthy limestone, and conglomerate, vitreous sandstone or quartzite, the shale and limestone predominating. In places, the shales are highly carbonaceous and sometimes show traces of coal, but thus far no coal beds of importance have been discovered in this formation. The sandstones are usually hard, with a vitreous fracture, and present the characteristic appearance of quartzites. The beds are often conglomeratic, the included pebbles consisting for the most part of pure-white quartz. The basal beds of the series in the Magdalenas, comprising a thickness of ten to fifteen feet, consist of a moderately coarse conglomerate interbedded with dark shale. While these beds rest apparently conformably upon the limestones below, the relations are undoubtedly those of unconformity. About 125 feet above the base of the series is a formation of coarse white quartzite or conglomerate in massive ledges separated by thin beds of shale. Some of the quartzite beds are filled with pebbles. Overlying this is a limestone formation eighty to ninety feet thick, in which appear some thin beds of shale and quartzite. At the base of this limestone formation is a thick-bedded dark-blue subcrystalline limestone six

[1] C. L. Herrick, *Jour. Geol.*, Vol. VIII, p. 115, 1900; *Am. Geol.*, Vol. XXV, p. 235, 1900; *Am. Geol.*, Vol. XXXIII, p. 310, 1904.

[2] C. R. Keyes, "Water-Supply Paper No. 123," *U. S. Geological Survey Report*, 1904.

feet thick overlaid by about twenty-five feet of shale and thin limestone above which occurs two feet of quartzite followed upward by fifty feet of compact bluish earthy limestone. It is at the contact of the shale and limestone formation with the conglomerate below that the "upper" or "surface" ore deposits occur at Kelly.

These Sandia beds are well exposed on the east slope of Mount Socorro, and northward in the Limitar Mountains. They also appear on the east side of the river opposite Socorro and elsewhere.[1] Southward, as stated above, there is a marked decrease in the porportion of sand and clay beds accompanied by an increase in calcareous sediments. The shaley beds which constitute the lower part of the escarpment near Hermosa are evidently the equivalent of the Sandia beds as represented in Socorro County, but farther south the distinction between the upper (Madera) and lower (Sandia) divisions of the Magdalena is not recognizable.

The thickness of the sediments referred to this division varies from 500 to 700 feet.

Madera limestone.—Overlying the Sandia beds in Socorro and Bernalillo counties is a dark-blue limestone, for the most part in thick beds alternating with other thin shaley beds and blue shale. The limestone contains many fossils of the same type as those found in the Sandia beds below, but owing to the extreme hardness of the rock specimens are difficult to obtain.

These limestones constitute the top of the ridge above Kelly, where they have a thickness of about 300 to 500 feet, having been partly removed by erosion. On Mount Socorro they reach a thickness of about 700 feet, while good exposures of the beds appear also in the Limitar Mountains. The Madera beds constitute the great limestone plate along the back slope of the Sandia Mountains, and upon this limestone plateau is located the little Mexican town of La Madera, from which the formation is named.[2]

Herrick[3] has described the lower part of the formation in the Sandias as consisting of dark limestone, while the upper beds are of massive, gray siliceous lime with an intervening sandstone or con-

[1] C. L. Herrick, *Jour. Geol.*, Vol. VIII, pp. 114, 115, 1900.

[2] C. L. Herrick, *Bull. Univ. of New Mex.*, Vol. I, p. 104, 1899.

[3] C. L. Herrick, *Jour. Geol.*, Vol. VIII, pp. 114, 115, 1900.

glomerate of inconstant thickness (40 feet at the maximum) which he calls the Coyote sandstone, from the canyon of that name in the south end of the Sandia Mountains.

THE MANZANO GROUP

Above the Madera limestone and resting unconformably upon it in the Rio Grande region, is a series of red and pink sandstones and shales with deposits of gypsum capped by a prominent formation of limestone. These red sandstones and shales constitute in part the beds usually regarded as the equivalent of the Kansan Red Beds called Permian, while some of the upper beds were thought by Herrick to be Jura-Trias in age.

The writer's observations of these formations, though limited, led him to regard them as belonging to the Pennsylvanian series, a conclusion fully established by the more detailed studies of W. T. Lee,[1] of the U. S. Geological Survey. The series of variegated sandstone, shale, and gypsiferous beds was described by Herrick[2] from the Manzano Mountains, northeast of Socorro, in 1900, and by him named the Manzano series. In the southern part of the region a limestone formation several hundred feet in thickness overlies the red beds, and from it Lee obtained a large collection of fossils which are distinctly allied to those obtained from the red series, the whole, as stated by Dr. Girty,[3] being distinctly Pennsylvanian, though markedly differing from the fauna of the lower, or Magdalena, group. Northward in Bernalillo County the upper limestone member is absent, and variegated sandstone and shale beds, similar to those of the Morrison formation, rest upon the pink sandstones, with an intervening erosion unconformity.[4] Lee considers the Manzano group lithologically separable into three divisions, the lowermost of which consists principally of dark red sandstones interstratified with red sandy shales and some thin beds of bluish-drab earthy limestones. At the base of the

[1] *Jour. Geol.*, Vol. XV, pp. 52–58, 1907.

[2] *Jour Geol.*, Vol. VIII, pp. 115, 116, 1900; *Bull. Univ. New Mex.*, Vol. II, Pt. 1, Fascicle No. 3, p. 4, 1900.

[3] Quoted by Lee, *Jour. Geol.*, Vol. XV, p. 54, 1907.

[4] The description and classification of the Manzano beds is to appear in a forthcoming publication by Messrs. Lee and Girty.

formation is a limestone conglomerate the pebbles of which were derived from the underlying Madera beds. Above this, as seen in the hills east of Socorro, is a coarse red granitic quartzite conglomerate. The thickness of the red sandstone division varies from 400 to 800 feet. Overlying these beds occur alternating strata of yellow, pink, and white sandstones and shales with lenses of gypsum and a subordinate amount of limestone. In places the gypsum is massive and reaches a thickness of 140 feet. The total thickness of this formation ranges from 500 to 1,000 feet. The uppermost division of the Manzano group consists for the most part of gray limestone in which an abundant fauna occurs. These beds are well developed in the mountains east of Socorro and southward in the San Andreas Mountains east of Engle, but were not observed on the west side of the Rio Grande. According to Lee this limestone is not present in the Sandia Mountains. The total thickness of the formation is from 300 to 500 feet. Several miles northeast of Socorro, and in plain sight from this place, are a number of minor elevations called the Coyote Buttes. At this locality the Manzano beds are well exposed in the west face of the hills, the strata dipping sharply to the northeast. The red sandstones of the lower division occur on the west of the Magdalena Range south of Kelly and along the east side of the Black Range from Fairview south to Kingston. The overlying beds were not observed in the Black Range region.

Heretofore these red-sandstone formations have been at times confounded with the Red Beds supposedly of Permian and Triassic age, but according to Dr. Girty,[1] who has made a study of the fossils collected from them by Mr. Willis T. Lee, of the Survey, they are undoubtedly Upper Carboniferous and correspond in their relations to the upper part of Richardson's Hueco formation in Texas and the Aubrey in the Grand Canyon region.

In the Mount Taylor region, sixty miles west of the Rio Grande, there are 1,200 feet of Upper Carboniferous red and yellow sandstones, according to Dutton, who identified them with the Aubrey and used that name for them.

Nomenclature.—While there have been published a great many papers relating to the region under consideration, very little detailed

[1] Personal communication.

work has been done, and the names applied to different formations have been in some cases not at all defined, while in others the descriptions can be interpreted only with the greatest difficulty. A few names, however, are well established. Herrick[1] applied the name Sandia beds, or Sandia series, to the alternation of shale, limestone, and sandstone which constitute the lower half of the Magdalena division in Socorro and Bernalillo counties in 1900, and his description is such that no difficulty is encountered in the application of this term. At the base of the formations east of Socorro is a bed of clay containing Carboniferous plants to which Herrick gave the name Incarnacion Fire Clay, but he expressly states, "There would seem to be no reason for separating the fire clay from the Sandia formation, it being but a local variation."[2]

The limestone formation overlying the Sandia beds he appears to have left unnamed, but to the bed of sandstone which occurs near the middle of the formation in the vicinity of Coyote Springs, Bernalillo County, he gave the name Coyote sandstone.[3]

The same author applied the name Manzano[4] to the series of red sandstone and other beds which overlie the rocks of the Magdalena division in the Manzano Mountains and adjacent regions. His description of these beds does not make it altogether clear whether he meant to apply the name to the lower red sandstone alone or to the whole series, including the gypsiferous beds, the chocolate-colored sandstones, and their accompanying shales and earthy limestones. It would seem, however, that the latter was his intention. He does not seem to have included under this name the limestone overlying the pink and yellow sandstones, which, as shown by Lee,[5] belong in the series.

In a recent paper, C. R. Keyes[6] presents a classification of the Carboniferous rocks of New Mexico in which several new names appear, but without adequate definition. The shale bed at the base of the Sandia formation he separates, giving it the name Alamito, and

[1] C. L. Herrick, *Jour. Geol.*, Vol. VIII, p. 115, 1900; *Am. Geol.*, Vol. XXV, p. 235, 1900; *ibid.*, Vol. XII, pp. 237–251, 1904.

[2] *Jour. Geol.*, Vol. XII, p. 242, 1904. [3] *Jour. Geol.*, Vol. VIII, p. 115, 1900.

[4] *Loc. cit.* [5] W. T. Lee, *Jour. Geol.*, Vol. XV, pp. 53, 54, 1907.

[6] C. R. Keyes, *Jour. Geol.*, Vol. XIV, pp. 147–54, 1906.

makes it the equivalent of a series to which the name Ladronesian is applied. No evidence in support of this separation is given, and Herrick specifically states that none exists. For the remaining part of the Magdalena division Keyes uses the term Manzanan. Even a cursory reading of Herrick's description is sufficient to show that these are not the beds for which the name Manzano was originally proposed. For subdivisions of the rocks included under his term Manzanan, Keyes uses, in addition to Herrick's terms Sandia beds and Coyote sandstone, the name Montosa for the limestone below the Coyote sandstone, and Mosca for that above. No evidence is given that will warrant the establishment of these formation names. Our own observations lead us to conclude the Coyote sandstone to be of local development and the subdivision of the Madera formation to be unsupported by the evidence thus far available.

Overlying his so-called Manzanan, the same author[1] notes a limestone formation which he calls Maderan. Evidently he regards this as the same formation which in an earlier paper he says is, in the Sandia Mountains, called the Madera limestone, and adds that it forms by far the most important portion of the Carboniferous in all the mountain ranges mentioned. From Herrick's description of the geology of the Sandia Mountains, which is corroborated by the studies of W. T. Lee,[2] of the U. S. Geological Survey, it is clear that the great limestone formation of the Sandias is the limestone which constitutes the upper half of our Magdalena division and comprises the formations to which in the same table[3] Keyes gives the names Montosa and Mosca, with the included Coyote sandstone. The discrepancies in this case are apparently due to confounding the Madera limestone in some places with the limestones at the top of the Manzano group. Inasmuch as the name Madera very appropriately applies to the limestone overlying the Sandia beds in the Sandia Mountains, it may well be retained for the upper formation of the Magdalena division.

In the following table is presented, in convenient form for comparison, the classifications of the Pennsylvanian rocks in the Rio Grande region by the different authors mentioned.

[1] "Water-Supply Paper, No. 123," *U. S. Geol. Survey Report*, p. 22, 1905.

[2] Personal communication.

[3] *Jour. Geol.*, Vol. XIV, p. 154, 1906.

Gordon and Lee, 1907				Herrick, 1900		Keyes						
						1904		1905		1906		
Series	Group	Formation	Character of Rocks									
Pennsylvanian	Manzano		Unconformity									
			Limestone. 300–500 ft.	Limestone	Jura-Trias	Cimarronian	Triassic	Red beds	Permo-Carboniferous	Moencopie shales	Cimarronian	Permian
			Pink or vermilion and yellow sandstones, shales and earthy limestones, and gypsum beds. 500–1,000 ft.	Manzano						Sandstone shales		
			Red sandstones and conglomerates with some earthy limestones. 400–800 ft.		Permian	Bernalillo shales		?		Capitan L. S. Eddy sandstone	Guadaloupan*	
	Magdalena (Gordon, 1907)	Madera	Unconformity	Limestone	Permo-Carboniferous	Madera limestone	Carboniferous	Madera limestone	Pennsylvanian	Maderan limestone	Maderan ("Hueco in part")	Pennsylvanian
			Limestones with some shales and sandstones. 600–1,000 ft.	Coyote S. S. Limestone	Coal measures					Mosca limestone	Manzanan	
										Coyote S. S.		
		Sandia	Alternating shales, limestones, and sandstones. Toward south nearly all limestones. 500–600 ft.	Sandia beds (or series)		Sandia limestone		Sandia quartzite		Montosa limestone		
										Sandia shales		
		Unconformity	Unconformity							Alamito shales	Ladronesian	

*Not known to be represented in Rio Grande region.—Gordon.

Editorial

RESOLVED that the Mississippi Valley Association of State Geologists expresses its belief in the desirability of a thorough reconsideration of the principles which should govern the nomenclature of geology, and its willingness to co-operate in any movement for the bettering of present conditions.

AND RESOLVED that copies of this resolution be sent to the secretary of the Geological Society of America, be presented to the conference of geologists now in session in Washington, and to Director Smith of the U. S. Geological Survey.

This is an action most heartily to be commended. We note with peculiar pleasure that the association desires *a thorough reconsideration of principles*, not a mere temporizing agreement for putting into more common and oppressive use current methods, some of which are good, some indifferent, and some bad. A special nomenclature is a grave burden to a science at best, but when it becomes positively bad, the affliction is grievous indeed. Geology does not suffer from this so much as the biological and mineralogical sciences, but it necessarily participates in their afflictions and has some special and quite unnecessary ones of its own. It is probably safe to say that several times as many people as are now interested in our science would be among its enthusiastic promoters, if its great truths had been habitually clothed in the plainest available terms in the literature of the past century. The history of the earth and of its inhabitants, the processes of its evolution, and the facts of its structure are inherently interesting, and if the story were so told that it could be read easily and intelligibly, it would give both pleasure and profit; but the current of the reader's enjoyment is so often needlessly checked by unintelligible terms, that he soon becomes weary and lays the annoying text aside for something less trammeled by pedantic toggery. This is not solely a layman's affliction. Geological readers of no mean literary and scientific attainments are all too frequently caught and held by the briars and brambles of our crudely technicalized literature. The fundamental sin is the offspring of the vanity of scholasticism. Could anything better characterize the typical scholasticus than our practice of using "syncline" for bent strata that outcrop divergently,

and "anticline" for those that outcrop convergently? The terms do not even become intelligible when the reader is told that they are "from the Greek . . . . , meaning . . . . ;" he must learn and *constantly remember* that there is a suppressed "downward" to be read after each of these terms. The "downward" is consistently suppressed, for it is just as plebeian as sag or arch, or any of the vulgar English equivalents which might have been used to tell the whole story in the first place. But the folly does not all lie in the vanities of classical erudition. It is just as bad to make "heave" mean a horizontal movement as to make "syncline" mean bent beds that diverge as they outcrop. The literature of science is full of phrases wrested from their current meanings and forced into special senses, which special and forced senses *must always be remembered*, if the reader would know what is meant. "Viscous" was a good word before it was criminalized. Starting with a liquid like molasses, we could once say that, as it was boiled, it became more and more viscous up to a maximum viscosity, beyond which, either by further boiling or by cooling, it became less viscous and more solid until it came to be distinctively rigid and brittle, a state which common people never thought of calling viscous. So, on the other hand, starting with glass, a very brittle solid, we could say that on heating it became gradually more and more viscous up to a maximum viscosity, beyond which it became more and more liquid and less and less viscous. Viscous then meant a certain peculiar intermediate state between the liquid and the solid, with a maximum viscosity midway, a phenomenon so common and distinctive as to need an appropriate term. Now, however, by a misguided technicalization the term is scarcely less than Mephistophelian in its competency to beguile the unwary.

But it was not this phase of the subject, we surmise, that the association had in mind. Its members are probably ready to accept the sins of the past, if they may avoid the afflictions of the future. They probably had in mind the "pernicious activity" displayed in certain quarters in putting new names in the place of old ones, sometimes better, often worse, under pretext of correlation, etc., without a sufficient basis for so doing either in the thorough study of the formations, or of the merits of the names, or of the principles involved, and without due regard to the economies of the profession or the conven-

ience of the public. The cheapest device for making the largest show of quasi-results in technical garb with the least investment of scientific capital known to our profession is found in giving new names to known formations, because of some real or imagined objection to the names in use, or because some new division may be thought to be better, or because some arbitrary "rule" is violated, or because of a premature assumption of the right of authoritative correlation. Certain excessive practices of this kind have reached a point where protest, if not censure, is merited. There are of course real occasions for new names and even for new systems of names, but every author is likely to overestimate the need of nomenclature in the case he has in hand, and every organization is likely to overestimate the weight of its authority. The practice of imposing new names should be held in reasonable restraint out of regard for the common convenience of the readers of the literature of the science, professional as well as non-professional.

More important than even this, however, is the desirability of keeping the path clear for a final and really satisfactory nomenclature when the appropriate historic, dynamic, classificatory, and other work that must precede a good and lasting nomenclature shall have been adequately done. This can be attained only by wide and careful study, guided by restraint, equipoise, and sagacity; and the results so reached should be approved by adequate trial before they are harnessed to final names. Pending this, the individual worker may well be allowed much liberty in the use of such terms as may suit his purpose, *if*—and this is a vital point—these are regarded as mere temporary and personal conveniences, and are held to be quite without claim to a place in an "adopted" nomenclature except as that claim shall rest upon inherent merit. The "adoption" and formal imposition of names, *as by authority*, is only tolerable when it is preceded by the only sanction of authority which the higher canons of science respect, *inherent merit based upon adequate investigation.*

The association is eminently wise in the adoption of its resolutions and it is to be hoped that the organizations to which it has addressed them will respond by a hearty co-operation, and that the end will be such wise control of the growth of our nomenclature as shall give it, at length, the highest practicable serviceability.

T. C. C.

The celebration of the hundredth anniversary of the founding of the Geological Society of London, which took place recently, was an event of more than ordinary interest in that it not only signalized the great age of the society, the oldest of all geological societies, but, in calling to mind how near the beginning of geological science it had its birth, as was done by the presidential address of Sir Archibald Geikie, it emphasized the comparatively rapid development of geology as a branch of knowledge. Almost all the advancement from the realm of speculation to that of established facts has taken place during the lifetime of the Geological Society, a very great part of it having occurred within the memory of the oldest geologists present at the meeting, and in fact having been accomplished to a considerable extent by their labors.

While the function of the Centenary meeting was almost wholly social, consisting as it did, of a reception of delegates by the president of the society, Sir Archibald Geikie, an address by him, and a banquet to all the guests in the evening of the first day, followed by another banquet and a general reception on the second, together with numerous smaller entertainments of a social character, there were extended geological excursions before the meeting and shorter ones afterward. Throughout these events there was such evidence of forethought and consideration for the comfort and welfare of the guests as to reflect great credit on those who planned and managed them, and to afford a new example of proverbial English hospitality.

The Centenary meeting was also interesting because of the representative character of the geologists whom it brought together from all parts of the world. For besides the large number of British and Colonial geologists in attendance, there were 94 from foreign countries, of whom 50 were from France, Germany, and America in nearly equal numbers; the other countries represented by smaller number being Sweden, Belgium, Holland, Russia, Austria-Hungary, Norway, Denmark, Switzerland, Egypt, Greece, Italy, Portugal, Mexico, and Japan, in the order given. The opportunity of renewing friendships and of exchanging ideas with colleagues from such widely remote regions was the most important feature of the meeting, and one that makes for a better understanding among geologists and a certain advancement of the science.

After the celebration in London the visitors in two groups were entertained most hospitably by the Universities of Cambridge and Oxford, and the honorary degree of Doctor of Science was conferred upon a number of the most distinguished Europeans: from Germany, Professor Ferdinand Zirkel and Professor Hermann Credner of Leipzig, Professor A. Penck of Berlin, and it was known that Professor Rosenbusch of Heidelberg would have received the degree had he been able to be present; from France, Professor Charles Barrois of Lille, Professor A. Lacroix and Professor A. de Lapparent of Paris; from Norway, Professor W. C. Brögger and Dr. Hans Reusch of Christiania; from Sweden, Professor A. G. Nathorst of Stockholm; from Switzerland, Professor A. Heim of Zurich; and from Belgium, Professor Louis Dollo of Brussels. That no honor was conferred at this time upon any geologist of the English-speaking peoples of America or of the British Colonies is remarkable, considering the quality and amount of work done by the older and ablest geologists in these vast territories. We trust that this inaction on the part of the great English Universities will not be misinterpreted as a lack of appreciation on their part of the attainments of the most distinguished of Colonial and American geologists, but will be attributed to causes not at present understood by those outside the Universities' councils.

J. P. I.

Reviews

Invertebrate Paleontology of the Upper Permian Red Beds of Oklahoma and the Panhandle of Texas. By J. W. BEEDE. (*Kansas University Science Bulletin*, Vol. IV, No. 3, March, 1907, pp. 115–72, Plates V–IX.)

It will be remembered by those familiar with the literature of the Red Beds of the Kansas-Texas region that in 1902 Dr. Beede first described, in this same periodical, a small invertebrate fauna from the Whitehorse sandstone of Oklahoma, concerning which he stated at that time that "there can be but little doubt that the age of these beds is Permian."

It will aid one in understanding the stratigraphy of this region to state that Professor Gould has classified the rocks of Oklahoma, from the base of the Permian upward, as follows:

(1) Enid formation, 1,500 feet thick, which "includes all the rocks of the Red Beds from the base of the Permian to the lowermost of the gypsum ledges;" (2) Blaine, 100 feet thick, containing the lower gypsum beds; (3) Woodward, 425 feet thick, in the upper part of which is the Whitehorse sandstone; (4) Greer, 275 feet thick, containing the upper gypsum beds; (5) Quartermaster, 300 feet thick, which is capped by the Tertiary.

The systematic portion of the present paper contains a further elaboration of the Whitehorse fauna together with a description of a new one from a sandstone in the Quartermaster formation in the Panhandle of Texas. In Professor Gould's classification the Quartermaster division is given as the highest one of the Red Beds and Dr. Beede says that "the fossils came from well up in this formation." It is also stated that the types of the entire Quartermaster fauna were sent Dr. T. W. Stanton, who reported that they were unmistakably Paleozoic.

Dr. Beede says that "these collections are of great importance, as they furnish the final evidence that the Red Beds, below the Dockum beds, of the Oklahoma-Panhandle region are Paleozoic in age. . . . . The faunas are somewhat heterogeneous as to origin. Some of the species seem to be directly derived from the Kansas Permian or Pennsylvanian, while others, as pointed out in the discussion of the species, are derived from the European Permian, especially that of Russia." The description of these faunas is an important contribution to American geology, since it relatively determines

the age of a considerable thickness of rocks which heretofore on lithologic and stratigraphic evidence had been "referred to anything from the Permian to the Tertiary."

The discussion of the faunas and the descriptive part are preceded by an excellent "Historical Review" in which the geologic literature of this region is very fully discussed. In this review certain facts are brought out which are important to those interested in the age of the upper Paleozoic deposits of Kansas. It is stated that "Gould has shown that the Whitehorse sandstone is identical with Cragin's Red Bluff formation of Kansas," which is well toward the top of the Kansan Red Beds. The Wreford limestone of Kansas, which in his later papers the writer has regarded as the provisional base of the Permian, as followed south into Oklahoma, changes into the Payne sandstone that has been traced by Kirk to the vicinity of Norman in the latter state, and is supposed to mark the base of Gould's Enid formation. "Cope, Cummins, and C. A. White have demonstrated that the Wichita (including the Albany) and Clear Fork beds of Texas are unmistakably Permian. . . . . Williston and Case have demonstrated that the lower Enid formation of Oklahoma is Permian and of similar horizon to some parts of the Wichita and Clear Fork divisions of Texas."

Dr. Beede states that vertebrate specimens from Cowley County in southern Kansas, described by Dr. Williston in 1897, came from the Garrison formation about fifty feet below the Wreford limestone. Dr. Williston in describing these specimens stated that "we have here an interesting series of forms, so closely resembling the species described by Cope from Danville Ill., that I cannot distinguish them specifically. It would seem to demonstrate the contemporaneity of the two formations, and also that of the Texas Permian, whence the species of all these genera have been described by Cope." The presence of these Permian vertebrates, together with a Permian flora in the Garrison formation, favors its reference to the Permian, and perhaps the Cottonwood limestone at its base is really nearer the line of division between the Pennsylvanian and Permian than the Wreford limestone at its top. The top of this former limestone is near the horizon originally suggested by the writer for a tentative line of division between these two systems. The identification of Permian plants by David White and Sellards, Permian insects by Sellards, Permian invertebrates by Beede, and Permian vertebrates by Williston and Case, from the Kansas deposits which have been referred to the Permian by the writer seem to support the correctness of that correlation and to demonstrate that the base of the Permian is certainly as low as the horizon of the Wreford limestone.

CHARLES S. PROSSER

Synopsis of Mineral Characters. By RALPH W. RICHARDS. New York: John Wiley and Sons, 1907. Pp. 99.

This is a compact little book, strongly bound in leather, and of convenient size for the pocket. Minerals, mineralogical terms and tests, are all arranged alphabetically. The descriptions are concise and accurate and include all the more essential properties of the species described. The book will be useful both to students in the laboratory and field, and to miners and others who are interested in minerals.

C. W. W.

Fifty-seventh Annual Report of the New York State Museums for 1903, containing the Twenty-third Report of the State Geologist, 1903. Albany, N. Y., 1905.

Contains articles on peat, the gypsum industry, abrasives, distribution of Hudson Schist and Harrison Diorite in part of the Oyster Bay quadrangle, the northeast extremity of the pre-Cambrian Highlands. In the appendices are "The Geology of the Vicinity of Little Falls, Herkimer Co.," by H. P. Cushing; "New York Mineral Localities," by H. P. Whitlock; "Report of the State Paleontologist, 1903," by J. M. Clarke; "Feeding Habits and Growth of *Venus mercenaria*," J. L. Kellogg.

Molybdenum. By E. C. ANDREWS. Pamphlet No. 4, Geological Survey, Mineral Resources, Department of Mines and Agriculture, New South Wales. Pp. 17. Sydney, 1906.

The ore of molybdenum is molybdenite in quartz. It is directly associated with intrusions of fine "sandy" granite about which the ore forms contact deposits. One mine produces practically all the molybdenite from New South Wales. Its output in 1904 was 25¼ tons, value £2,726.

Cambrian Faunas of China. By CHARLES D. WALCOTT. (Proceedings of the U. S. National Museum, Vol. XXIX, pp. 1–106. Washington, D. C., 1905.)

Faunas embracing 48 genera and 172 species are listed from three formations in the upper and middle Cambrian. Five new genera and about 125 new species and varieties are described. The upper Cambrian faunas are related to those of North America and northwestern Europe. This is a preliminary report, published in advance of a fuller one with plates, that will appear this year.

C. W. W.

The Petroleum Industry of Southeastern Illinois. By W. S. BLATCHLEY. Bulletin No. 2, Illinois State Geological Survey. Pp. 109, 5 plates. Urbana, Ill., 1906.

The report discusses the history of the petroleum industry in Illinois, the oil-producing rocks and their structure, theories of origin, mode of occurrence, and production of oil in the state. There is also a description of the various oil and gas fields. C. W. W.

The Composition and Character of Illinois Coals. By S. W. PARR. *The Distribution of the Coal Beds of the State.* By A. BEMENT. *Tests of Illinois Coals under Steam Boilers.* By L. P. BRECKENRIDGE. Bulletin No. 3, Illinois State Geological Survey, Pp. 86. Urbana, Ill., 1906.

Geology and Mineral Resources of Mississippi. By A. F. CRIDER. (Bulletin No. 283, U. S. Geological Survey. Pp. 99, 4 plates, including a colored geological map of the state.) Washington, D. C., 1906.

Four Cretaceous, seven Tertiary, and two Quaternary formations are described, generally with especial reference to their economic possibilities. The mineral resources include clays (which furnish nine-tenths of the state's income from mineral sources), ochre, glass-sand, cement rocks, and iron-ore. C. W. W.

Clays: Their Occurrence, Properties and Uses, with Especial Reference to Those of the United States. By HEINRICH RIES. New York: John Wiley & Sons. London: Chapman & Hall, Limited. 1906, pp. 290, 44 plates.

This book is a summary of our present knowledge of clays. It treats of the origin and the chemical and physical properties of clays, the kinds of clays, and the methods of mining and manufacture. The occurrences of clay are described by states, the clays of each geological period being treated separately. C. W. W.

Igneous Rocks of the Eastern Townships of Quebec. By JOHN A. DRESSER. (Bulletin of the Geological Society of America, Vol. XVII, pp. 497–522, Plates 67, 68.) Rochester, N. Y., 1906.

The rocks of southeastern Quebec present two petrographic provinces: I. (*a*) Porphyry-andesite series, extrusive and probably pre-Cambrian;

(*b*) Diabase-serpentine group, early Cambrian to late Silurian; (*c*) Granites, intrusive, late Devonian; (*d*) Later dikes. II. The Alkaline province of the Monteregian hills described by Adams. C. W. W.

Investigations Relating to Clays. By the UNITED STATES GEOLOGICAL SURVEY in 1905. (Extract from Bulletin No. 285, Contributions to Economic Geology, 1905.)

Contains: "Clays of Garland County, Ark.," by Edwin C. Eckel; "Clay Resources of Northeastern Kentucky," by W. C. Phalen; "Clays of Western Kentucky and Tennessee," by A. F. Crider; "Clays of the Penobscot Bay Region, Maine," by E. S. Bastin; "Clays of Cape Cod, Massachusetts," by Myron L. Fuller; "Notes on Clays and Shales in Central Pennsylvania," by George H. Ashley; "Bentonite of the Laramie Basin, Wyoming," by C. E. Siebenthal. C. W. W.

The Eurypterus Shales of the Shawangunk Mountains in Eastern New York. By JOHN M. CLARKE. Bulletin 107, N. Y. State Museum, pp. 295–310, plates 1–8. Albany, N. Y., 1907.

This important little paper gives conclusive paleontologic evidence for transferring the stratigraphic position of the Shawangunk Grit from the base of the Silurian to the Salina. C. A. Hartnagel had already reached the same conclusion from stratigraphic studies. His views are presented in another paper in the same bulletin. C. W. W.

Geology of Diamond Head, Oahu, Mokokea Caldera. By C. H. HITCHCOCK. (Bulletin of the Geological Society of America, pp. 469–96, plates 59–66.) Rochester, N. Y., 1906.

"Diamond Head is a tuff cone thrown up explosively from beneath the level of the sea, and is to be compared with the Monte Nuovo, near Naples. It was ejected through fossiliferous limestones of Tertiary age, probably Pliocene."

Mokokea Caldera is on the southwest slope of Mauna Loa. The order of events in its history is given, including recent eruptions.

C. W. W.

Recent Publications

—Rotch, A. L. Proof of the Existence of the Upper Anti-Trade and the Meteorological Conditions at Lesser Heights in the Northern Tropics. [Blue Hill Meteorological Observatory, Mass.]

—Rowe, Ph.D., J. P. Montana Coal and Lignite Deposits. [University of Montana Bulletin No. 37. Geological Series No. 2. Missoula, Mont., 1906.]

—Scalia, S. Sopra le Argille Postplioceniche della Vena Presso Piedmonte Etneo (Prov. di Catania). [Estratto dal Rend. della R. Accademia delle Scienze Fisiche e Matematiche di Napoli Fascicolo 4°—Aprile, 1906.]

—Schreiner, O., and Failyer, G. H. The Absorption of Phosphates and Potassium by Soils. [U. S. Department of Agriculture, Bureau of Soils Bulletin No. 32. Washington, 1906.]

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